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HANDBOOK OF MACHINE BUILDING MATERIALS

BY: G. I. Pogodina-Alekseyev

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ACID-RESISTING CHROMIUM STEELS (16-20% Cr) OF THE SEMI-FERRITE AND FERRITE CLASSES

The properties of semi-ferritic steels depend to a considerable extent upon the quantitative relationship of ferrite and austenite in the structure of the steel when it is heated to the temperature of thermal treatment. When the ferrite component predominates, the steel, if heated to a temperature above 850° C, acquires a great aptitude for grain growth. This leads to large-grained structure and brittleness, which are not eliminated by subsequent thermal treatment, also to lower resistance and corrosion (see fig. 9). In connection with this, the hot mechanical processing of semi-ferritic steels must be finished at the lowest temperatures possible in order to obtain smaller grains. In such a case subsequent annealing at 760-800° C, after hot deformation conserves in the steel a small-grained structure and fully satisfactory mechanical and technological properties.

Heating of semi-ferritic steels to temperatures of 760-800° C also causes a more even distribution of chrome concentration in the hard solution,

and, consequently an improvement of resistance to corrosion. Therefore, welded joints of parts made of 17% chrome steel must be subjected immediatly after welding to thermal treatment in order to increase corrosion resistance. 17% chromium steels show high corrosion resistance in cold nitric acid of any concentration. In hot nitric acid (at 60 - 70°C) 17% chromium steels are resistant when acid concentration does not exceed 66%, while in boiling nitric acid they resist a concentration of up to 50-60%.

high-temperature oxidation

17% chromium steels may be used as ~~scale~~-resistant materials at temperatures up to 850-900° C. With some increase of silicon content, the steel becomes resistant also in hot combustion gases rich in sulphur. However, an inclination to grain growth when heated (above 850° C) and low heat-endurance, limit the use of 17% chromium steel.

A positive influence upon the properties of 17% chromium steels is exerted by post-charging with titanium and niobium, as they eliminate the appearance of austenite at high temperatures and improve corrosion-

resistance of welded joints in the seam zone. (58),(59).

The action of titanium is effective only when all the carbon in the steel combines into titanium carbides. This is achieved with a titanium content 6- to 8 times larger than that of carbon. Similar results are produced by postcharging with niobium, if its content exceeds that of carbon 8- to 12 times.

Postcharging 17% chromium steel with titanium and niobium also has a favorable effect upon the mechanical properties of welded joints, especially after arc welding. However, in autogenous welding of 17% chromium steels containing titanium and niobium, and with the use of chrome-nickel steel of type 18-8 (0.05% C) as welding rod material, the welded seams still have low plasticity. (58).

HIGH-TEMPERATURE OXIDATION-RESISTANT CHROMIUM STEELS (25-30% Cr) OF THE FERRITIC CLASS

Ferritic steels containing 25 to 35% chromium are used as high-temperature oxidation-resistant material in making furnace muffles, retorts, jackets of thermocouples and similar articles. When heated to temperatures above 850° C, the steels acquire a large-grained structure and brittleness which cannot be eliminated by thermal treatment.

Heating to 475° C or slow cooling from high temperatures , when the steel remains sufficiently long at a temperature around 475° C imparts to the steel still greater brittleness and decreases its corrosion resistance. The higher the chromium content is in the steel, the greater this brittleness. (53),(55),(60).

Satisfactory mechanical and technological properties are obtained in steels of the ferritic class only in cases when, after hot mechanical processing and short-time annealing at 760-780° C, the steels acquire a small-grained structure.(2). Cooling

Fig.33. Dependence of the mechanical properties of 27% chromium steel on heat time at 475° C.

Fig.34.The influence of continued heating at rising temperatures on restoration of plasticity of 27% chrome steel after preliminary heating at 475° C in the course of 500 hours.

Fig.35.The influence of 1,000 hour heating at different temperatures on the hardness of alloys of the system iron-chrome.

(Note: Not previously sent; caption included in space for figure within text, but curves were not described)

Fig. 33

The dependence of the mechanical properties of 27% chromium steel

on heat time at 475° C.

notation in extreme upper left hand corner (illegible)

ordinate: KG/mm^2

first curve from top b (subscript illegible)

second curve from top b (subscript illegible)

third curve from top (illegible)

abscissa (hours)

Fig. 55: The influence of 1000 hour heating at different temperatures on the hardness of alloys of the system iron-chrome

abscissa: temperature of heating

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FIG. 34: The influence of continued heating, at increasing temperatures, on restoration of plasticity of 27% chromium steel after preliminary heating at 475° C, over 500 hours.

abscissa: elongation

ordinate: hours

after this annealing must be done in such a way, that the temperature range of 450-520° may be passed as quickly as possible.

The change in the mechanical properties of chromium steel in dependence upon the time length of heating at 475° C, is shown in fig. 33. Brittleness is most easily detected by impact tests of notched samples. Some investigators point out that a decline of impact toughness appears already after one hour at 475° C.

Subsequent heating to high temperatures may lead to a restoration of plasticity in 17% chromium steel which evidently was subjected to 500-hour heating at 475° C and was in a brittle state (fig. 34).

Brittleness in chromium steel may appear in consequence of welding, especially of massive parts. In such cases it is recommended to subject the welded parts to an additional annealing at around 800° C.

A second kind of brittleness in highly chromous steels manifests itself with heating to a temperature of the order of 700° C and is conditioned by the evolution of the σ phase. (fig. 35).

Postcharging with alloying elements exerts a great influence upon the development of brittleness with a heating to 475° C. Thus, a postcharge

with around 1% Mo or over 2.45% Mn accelerates the development of brittleness. A similar influence upon the brittleness of chromium steels is exerted by silicon, molybdenum, carbon, and aluminum. Small quantities of nickel evidently increase, while small quantities of nitrogen decrease brittleness of highly chromous steels at 475° C.

27% chromium steels have high resistance to oxidation, among other conditions, also at temperatures of up to 1100° C in an atmosphere of combustion products of fuels with a heightened sulphur content.

In heat-resistance the 27% chromium steels, like the 17% chromium steels, differ little from low-alloy and carbon steels, but they are inferior to 5% chromium steels postcharged with molybdenum.

An essential defect of 27% chromium steels is their great inclination to grain growth at heating temperatures above 800-850° C and the formation within them during welding of a coarse-grained structure that cannot be eliminated by thermal treatment.

Alloying of highly chromous steels with nitrogen leads to grain size reduction in the initial condition and to a slow-down of the speed

of grain-growth during heating.

Nitrogen-containing chromium steels obtain their best mechanical properties after tempering at temperatures starting from 1100-1150° C. An annealing at temperatures around 800° C causes the development of nitrides in a sub-microscopic form and brittleness. This limits the use of nitrogen-containing chromium steels.

A combination of high mechanical and technological properties is reached in cases when 4-to 5% of Ni is added to 20-23% chromium steels simultaneously with nitrogen (0.25-0.35% N). In consequence, steels with an austenitic structure are formed, which in their properties are close to chrome-nickel steels of type 18-8.

In detail the properties of nitrogen-containing steels are described in articles (6), (C?), (9), (2) and (53).

CHROME-NICKEL AND CHROME-MANGANESE-NICKEL STEELS WITH AUSTENITIC STRUCTURE

Addition of nickel or manganese to iron-chrome alloys contributes to the widening of the γ region. With definite contents of nickel the change (or transformation) $\gamma \rightarrow \alpha$ during cooling is suppressed, and the alloys attain a completely austenetic structure. Figure 36 shows a structural diagram of chrome-nickel steels.

In chrome-manganese steels, because manganese is less effective as an austenite-forming element, structures of intermediate type (austenite + ferrite or austenite + martensite) are more developed. (22), (60).

Alloying of chrome-nickel steels causes a change in the position of regions occupied by the phases α, γ and $\alpha + \gamma$ on diagrams of condition. (or phase diagram) The effectiveness of the influence of the alloying elements upon the formation of ferritic or austenitic structures is determined by the following: An increase in the content of chromium, titanium, niobium, silicon, tantalum, aluminum and molybdenum contributes to the formation of a ferritic phase in proportion to the quantities of these elements in the contents. An increase in the contents of nickel, nitrogen, carbon, and manganese acts in the opposite direction and contributes to the widening of the region of austenite and to greater stability of austenite.

To account for the summary (or total) influence of the alloying elements upon the structure of chrome-nickel steel a number of empirical formulae is offered. (69)

The graphic interpretation of one of these formulae, usable also for determining the composition of cast austenitic steel, is given in fig. 37. (68).

By a number of works (11),(12), (58), (54), it was established that the presence in the metal of welded seams of small quantities of ferrite is even beneficial because it decreases the formation of hot cracks.

During prolonged heatings at 700-800° C or during slow cooling from temperatures of 900-950° C of chrome-nickel steels, a brittle intermetallic α-phase (fig. 38) is formed in them. In a number of cases this component appears mainly along the limits of grains and imparts to steels an exceptionally high brittleness.

A heating of chrome-nickel steels to temperatures of 900° C, and above, leads to a dissolution of the brittle α-phase. (73).

In recent time it was established that the α-phase appears in the majority of chrome-nickel steels, which have a widespread industrial application, among them is steel of type 18-8 postcharged with Mo and Nb, in steels of type 25-20, 25-12, and others. (73).

The emanation of the alpha phase may proceed either directly from austenite or through ferrite.

It was established that alloys, which contain an α-phase in their structure have lower resistance to spalling from the actions of numerous

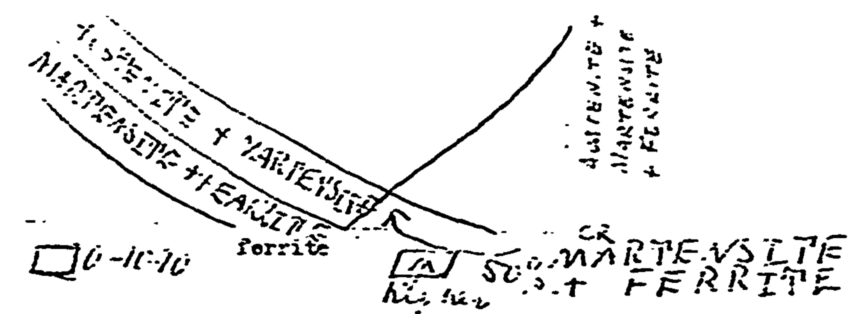

Fig.36. Structural Diagram Chrome-Nickel Steel (0.07 -0.1?% C; 0.30 - 0.48% Mn;0.23-0.37% Si)(69).

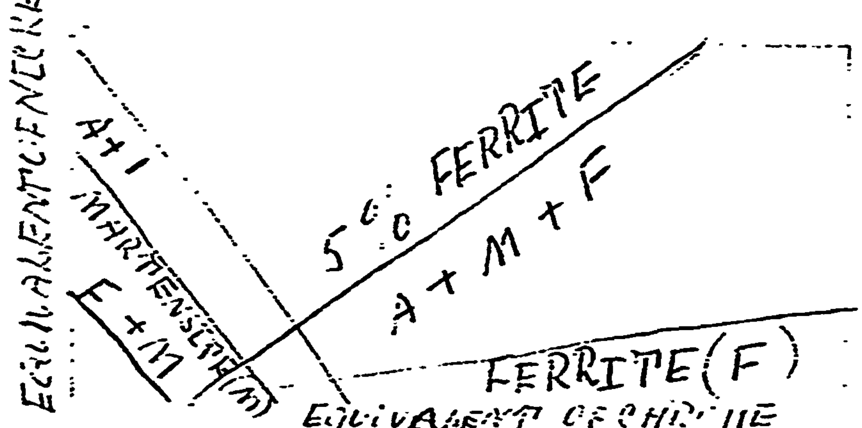

Fig. 37. Structural Diagram for casting chrome-nickel steel.

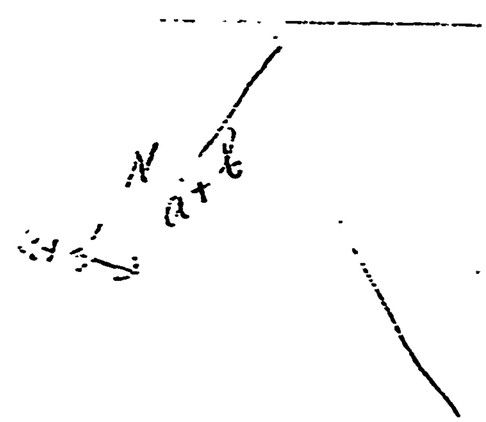

Fig.38. Phase conditions of regions in the system Fe-Ni-Cr for temperatures of 650 and 800° C.

heatings and coolings (thermal changes) than have alloys without an

α -phase-

A decrease of silicon and chromium content contribute to greater stability of the alloys against the formation of α -phase, which decreases the spalling of steel while in use.

Steels of type 25-12 are more susceptible to the development of α-phase and to spalling because they have a smaller content of nickel, namely, of the element which contributes to the development of austenite.

The addition of silicon (2%) assists, during protracted exposures to thermal treatment, the formation of the α-phase. Sometimes in this steel the α-phase is emitted in the form of a very small dispersing, but evenly distributed particles. In these cases the presence of such particles is even useful because it increases heat-endurance.

Cold-deformation of chromo-nickel steels increases the quantity of α -phase evolved during repeated heating. (73).

The stability of austenitic structure in chrome-nickel steels is also connected with changes in the solubility of carbon (carbides) with temperature changes. (2), (70), (71).

Many chrome-nickel steels, including those of type 18-8, have in the tempered state a sufficiently stable austenitic structure, which does not disintegrate at temperatures below 400° C.

Repeated heating of chrome-nickel steels within the temperature range of 450-900° C or slow cooling within this range, causes an evolution of excessive phases in the form of chrome carbides of type $Cr_{23}C_6$. (89),(90), (91),(92),(93), (64), (121),(97).

The appearance of these carbides is most frequent along grain limits and is accomplished by depletion of the bordering layers of chrome, in consequence of which the steel acquires an inclination toward inter-crystalline corrosion, when it is affected by aggressive mediums. (71),(2).

In chrome-nickel steels the inclination toward inter-crystalline corrosion, as a consequence of repeated heating, manifests itself in different degrees depending upon carbon content, and its force is in proportion to the magnitude of that content. (fig.39) (139).

With protracted heatings at temperatures of 500-700° C, even steel with a carbon content of 0.025-0.03 % acquires an inclination toward inter-crystalline corrosion. In these cases, it is necessary to use chrome-nickel steels postcharged with such strongly carbide-forming elements as titanium.

and niobium.

Austenitic chrome-nickel steels have a number of peculiarities conditioned by their structure: non-magnetism, non-hardening by tempering, increased heat-endurance, and as a rule, good weldability.

The most widely used chrome nickel steels have comparatively satisfactory characteristics of toughness and very high elastic properties. (see table 2).

Toughness characteristics of chrome nickel steels can be considerably improved by cold hardening (cold rolling, (76),(77),(78), drawing, and stamping in a cold state). The limit of strength may be thus heightened to 120 kg/mm^2 for sheets or strips and to 180-260 kg/mm^2 for wire. The yield point increases to 100-220 kg/mm^2. (2), (76), (78). Simultaneously plastic properties decline and relative elongation falls to 10-18%. Yet, cold-deformed austenitic chrome-nickel steel conserves a sufficient reserve of plasticity to allow bending, extrusion, and even stamping while making various items.

At room temperature austenitic chrome-nickel steels have a lowered thermal conductivity. However, at high temperatures the difference in thermal conductivity of austenitic chrome-nickel steel, and of steels of the ferritic

class, decreases.

Austenitic steels have high coefficients of linear expansion, which increases with the increase of temperature. (fig.41).

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Austenito-ferritic steels have higher properties of toughness than merely austenitic steels (E1810 and E1611), but they also have lowered plasticity and a more sharply expressed anisotropy of properties in deformed, and especially, in rolled materials.

Welded joints in these materials have greater toughness than welded joints in austenitic steels.

SEK

Fig. 39. Tendency of 18-8 steel to intercrystalline corrosion depending on carbon and time of soaking.

al 'cm-SEC'
LAL 'SM-SEC'

heat conductivity

Fig.40. Heat conductivity of different steels from temperature tests 1-ARMKO;2-nickel; 3-steel with 5% Cr; 4-steel with 17% Cr;5-steel type 18-8; 6- steel type 25-20.

Fig.41- Dependence of the mean coefficient of expansion from temperatures:1-steel 1Kh18N9T; 2- steel type 25-20 with additional Si;3-steel type 25-12; 4-steel Kh5;5-steel Kh17;6-steel Kh27.

The existence in these steels of a double-phased structure structure manifests itself unfavorably during hot processing by pressure , hot rolling, and especially in broaching pipe stock. (95),(136).

Austenite-ferritic ageable steels of type 17-7 postcharged with titanium and aluminum, in which during heating to 450-550° C, a development of high-dispersion phases causes an increase of toughness, begin to be widely used as a highly tough and heat-enduring material intended to work at temperatures not above 500° C.

The properties of thermal conductivity and of fluctuations in volume in austenito-ferritic steels are intermediate between those of ferritic and austenitic steels . The behavior of these steels depends upon the quantitative relationship of the phases.

During the disintegration of austenite in austenite-martensite steels, a great change of the coefficient of linear expansion takes place. (2),(22).

THE COMPOSITION AND PROPERTIES OF CHROME-NICKEL STEELS OF TYPE 18-8 AND OF TYPE 18-8 WITH TITANIUM OR NIOBIUM

Chrome-nickel steels with small carbon content (<0.06% C) of brand 0Kh18N9 has a comparatively limited use, mainly as electrode wire for welding steels of brands 1Kh18N9 and 1Kh18N12B. The corrosion resistance of these steels and their welded joints depends to a great extent upon carbon content.

The smaller the carbon content, the higher the resistance. In this case, it is best to use steel with a carbon content of 0.03-0.04% C, taking care that the total carbon content in the welded seam does not exceed 0.05- 0.06% C (fig. 39).

Steel 18-8, even with a very low carbon content (0.03-0.06% C) is not usable for long periods of work at 500-800° C. without its aftercharging with titanium or niobium, because in these conditions it still acquires an inclination toward inter-crystalline corrosion and disintegrates quickly under the influence of strongly aggressive mediums.

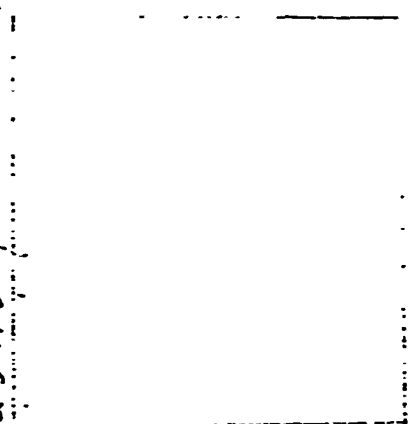

Fig. 42- Influence of continuous preliminary heating during different temperatures of tempered cast chrome steel with 0.12% C,19% Cr, and 9% N on corrosion resistance in boiling nitric acid.

Steels with larger carbon content, those of brands 1Eh18N9 and 2Khk8N9 acquire a very strong inclination to inter-crystalline corrosion when they are subjected even to transitory heating (for instance in welding) within a range of moderate temperatures. Therefore, they are used for the making of items, which by the technology of their production are not subjected even to momentary

heating within the range of moderate temperatures, or which also after welding are tempered for austenite.

Fig. 42 shows the influence of heating duration at different temperatures of tempering cast steel 19-8 containing 0.12% ... in boiling 65% nitric acid. Tempering at from 980–1200° C restores corrosion-resistance of the steel very quickly.

Basically, the steels of brands 1Kh18N9 and 2Kh18N9 are used as cold-hardened material for making light and lightly tough parts of air-planes, buses, etc.; which are to be joined by spot or roller arc welding. (2),(76),(77),(78). Chrome-manganese-nickel steels of brand Kh13G9N4 (E1100) is also used for the same purposes. (2),(79).

Steel Kh13GN4 has very good corrosion resistance in atmospheric conditions and in a number of not very aggressive mediums. (79),(80).

The properties of chrome-nickel steels at high temperatures and the changes that proceed in them are pointed out in articles (81),(82),(83),(84),(85),(86),(45), and (2).

The most correct solution of the problem of eliminating inter-crystalline corrosion in chrome-nickel steels of type 18-8 with titanium (steel of brand E1823) or with niobium is a sharp lowering of carbon content

(come to 0.03 or at least to 0.05%). This low carbon content is necessary in order to eliminate corrosion of the cutting type, which develops along the junction zone of weld metal and base metal.(12) and (116).

Corrosion resistance of steel 1Kh18N9T in nitric acid depends to a great extent upon the composition and the state of the steel and upon the conditions of its thermal treatment. Steel 1Kh18N9T has a very low corrosion resistance in a hot-rolled state. Therefore, items made from rods and forgings must be subjected to tempering at 1050° C and cooling in water or in air.(123).

It has been established that overheating of steel during thermal treatment or during welding, imparts to articles made of steel 1Kh18N9T an inclination toward inter-crystalline corrosion, especially when the correspondence of titanium and carbon contents is on the lower limit according to the formula of GOST (All-Union Standard) 6132-58. (8)

A stabilizing annealing, consisting of a two-hour heating at 870-900° C, when applied to hot-rolled steel, eliminates in the majority of cases, the tendency toward inter-crystalline corrosion, but it does not always secure high corrosion-resistance in nitric acid. Tempering at, from 1050° C, and 2-hour heating at 870° C produces better results because this does not impart to steel any inclination toward inter-crystalline corrosion and secures high corrosion-resistance to nitric acid, even after the heating at 650° C for 2 hours. (tab.8)

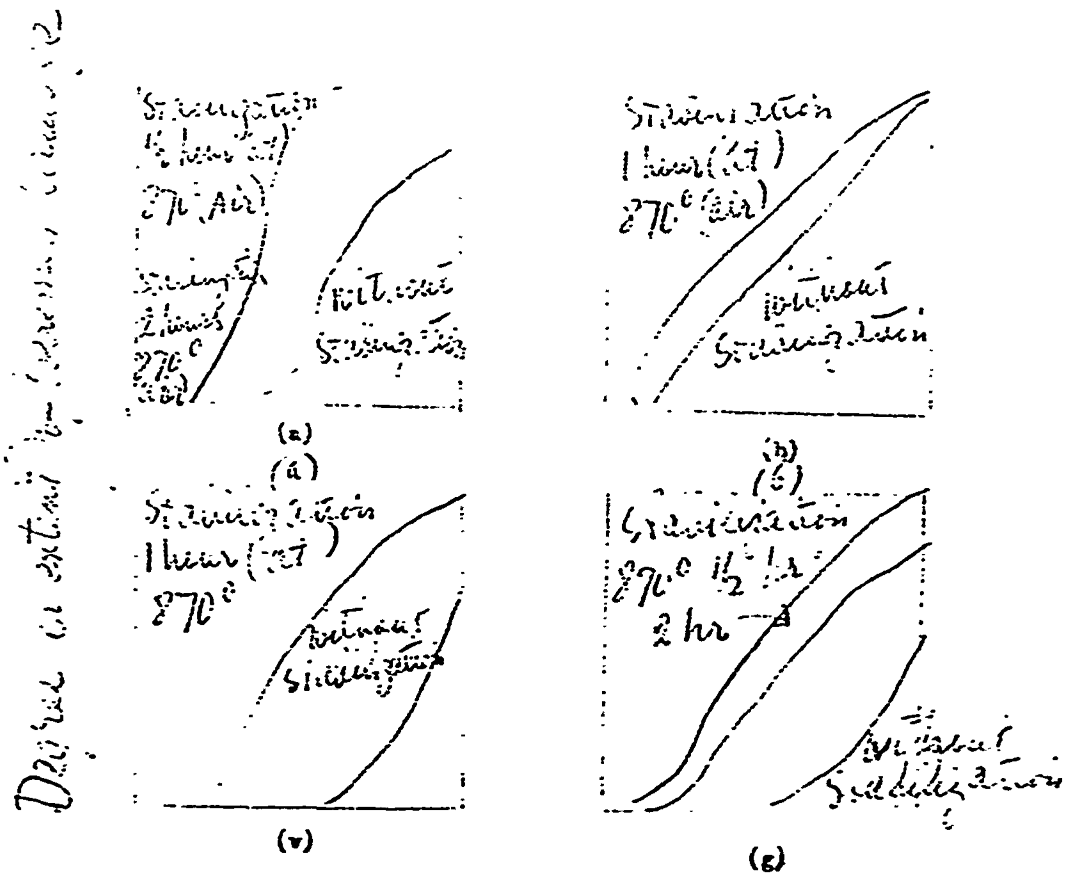

Fig. 43. Influence of the ratio of the content of titanium to carbon and heat-treating on the inter-crystalline corrosion of chrome-nickel steel 18-8; (a) hardening with 980° C in water (b) hardening with 960° C in air (v) hardening with 1050° C in water (g) hardening with 1050° C in air.

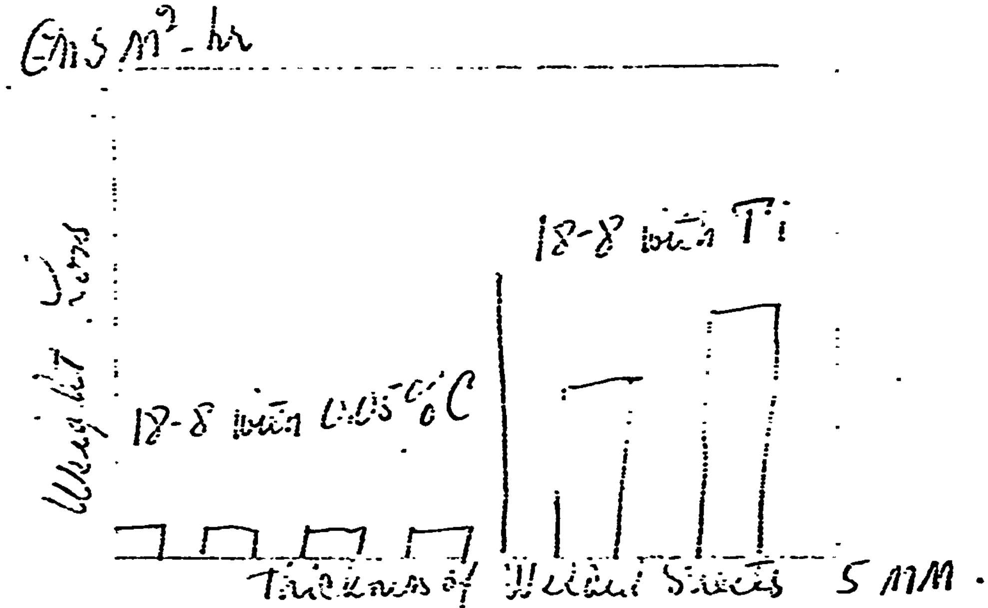

Fig.44. Influence of addition agents of titanium on corrosion resistanse of sample welding from 18-8 steel with titanium, welded from layers of different thicknesses I-Loss of weight during first 100 hours, tested in boiling 50% nitric acid - II- During the second 100 hours of testing.

8. Corrosion Resistance of Austenitic Chrome-Nickel Steel with Additions of Titanium in Boiling *0% Nitric Acid With G/M^2 Hours (123)

HEAT	Supplementary Heat Treatment	Heat Treatment Materials			
		Initial Material at Delivery	2 hours at 870° C, Cooling in Air	1 Hour at 1050° C, Cooling in Air	1/2 Hr, at 1200° C Cooling in Water
A					
A	hours				
V					
V	hours				
I					
I	hours				

* Material ********* * *********** in austenitic state

** Hot-Rolled Rod Material

It has been established that the addition of titanium to 18-8 steels exerts a detrimental influence on the corrosion-resistance of welded seams. In comparison with 18-8 steel containing 0.05% C, the corrosion-resistance of welded joints of 18-8 steel with titanium becomes considerably worse with increase of sheet thickness. (fig.43 and 44).

Fig.45. Influence of Aluminum content in 1X18N9T steel on rate of corrosion in 65% boiling nitric acid: A - 18.3% Cr and 12% Ni,0.67% Ti; B-19.2% Cr,11% Ni0.52% Ti; V- 19.6% Cr,10.5% Ni, 0.55% Ti; G- 20.5% Cr,10.4% Ni,0.60% Ti

In article (87) it is pointed out that aluminum, which usually is not controlled by chemical analysis, exerts great influence when the content of chromium in the steel increases and the content of nickel decreases. (fig.45)

It has been established that the more ferrite there is in steel 1X18N9T, the lower its corrosion-resistance in different media. The more ferrite there is in the steel, the greater is the difference between the periphery and the middle of a zone and the greater the difference of contents in these parts of the zone.

FIG. 45. Influence of aluminum content in 1Kh13N9T steel on rate of corrosion in 65% boiling nitric acid: A 18.3% Cr and 12% Ni, 0.67% Ti; B - 19.2% Cr, 11% Ni, 0.52% Ti; V-19.8% Cr, 10.5%, Ni, 0.55% Ti; G- 20.5% Cr, 10.4% Ni, 0.60% Ti

Ordinate: Rate of corrosion (mm/yr)

When the distribution of the ferritic component in the steel was sufficiently uniform, no differences in corrosion-resistance of different zones of 1X18H9T steel in nitric acid, and in a number of other mediums were detected. (124). In this case no difference manifests itself between the corrosion-resistance of purely austenitic steel and of austenite-ferrite steel. (2), (124)

No connection whatsoever could be established in the steel between the inclination toward inter-crystalline corrosion and the quantity of the -phase component (1-21%).

In cases where parts are intended to work at high temperatures in corrosively-aggressive mediums or when they, after work at high temperatures, are subjected to the action of such mediums, the content of titanium and niobium in the steel must be sufficiently high (138) in relation to carbon. The properties of these steels are elucidated in detail in article (176).

CHROMIUM-NICKEL STEEL OF TYPE 18-12 WITH MOLYBDENUM

The addition of chrome-nickel steels of types18-8, 18-12, and 16-13 with molybdenum increases their corrosion-resistance in a number of chemically aggressive mediums: in diluted sulphuric acid, in solutions of sulphate alkali used in the paper-making industry, in solutions of calcium hypochloride, etc.

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No connection whatsoever could be established in the steel between the inclination toward inter-crystalline corrosion and the quantity of the -phase component (1-21%).

In cases where parts are intended to work at high temperatures in corrosively-aggressive mediums or when they, after work at high temperatures, are subjected to the action of such mediums, the content of titanium and niobium in the steel must be sufficiently high (130) in relation to carbon. The properties of these steels are elucidated in detail in article (126).

CHROMIUM-NICKEL STEEL OF TYPE 18-12 WITH MOLYBDENUM

The addition of chrome-nickel steels of types18-8, 18-12, and 16-13 with molybdenum increases their corrosion-resistance in a number of chemically aggressive mediums: in diluted sulphuric acid, in solutions of sulphate alkali used in the paper-making industry, in solutions of calcium hypochloride, etc.

The addition of molybdenum to these steels also increases their heat-endurance properties, which are utilized in gas turbine and other installations.

Chrome-nickel molybdenum steels of type 18-12-3 acquire with a content of more than 0.07% carbon a tendency toward inter-crystalline corrosion during welding or slow cooling and, especially, during protracted heating within the range of moderate temperatures. When affected by aggressive mediums these steels are very quickly destroyed by inter-crystalline corrosion. In such cases it is expedient tp use chrome-nickel-molybdenum steels (with additions of titanium) of brands Khl8Nl2M2T and Khl8Nl2M3T.

By itself, adding molybdenum to chrome-nickel steels decreases the tendency toward inter-crystalline corrosion to a certain extent, but such corrosion is eliminated completely and only when the carbon content is very small (up to 0.03%). The conditions under which chrome-nickel-molybdenum steels acquire a sufficiently complete resistance to inter-crystalline corrosion are pointed out in article (70). It is an increase in the quantity of the ferritic phase in these steels that increases their resistance to inter-crystalline corrosion.

Table 9 shows the corrosion resistance of chrome-nickel-molybdenum

Table 9 - Corrosion-Resistance of Type 18-8-3 Steel (0.06% C; 0.17% N_2; 0.38% Ti) in Various Mediums in mm/year

Heat Treatment	In Boiling 65% HNO_3		35% H_2SO_4 at 40° C	20% H_2SO_4 at 40° C	5% H_2SO_4 at 80° C	1% HCl at 40° C
	I Period	II Period				
1150° C (Air)						
1150° C (Water)						
1150° C (Water - 20 min. 850° C)						
1150° C (8 hrs. 750° C)						
1150° C (4 hours 850° C)						

If the molybdenum content in type 18-12 steel with 0.03% C does not exceed 2 %, then boiling nitric acid does not produce any great destruction, notwithstanding the presence of the ferrite component in the steel. (70).

A large molybdenum content, even with high content of nickel, sharply decreases the corrosion-resistance of the steel in boiling nitric acid. This is explainable by the formation of the α-phase, which contains a large quantity of molybdenum. (fig.46)-(126),(130).

The corrosion resistance of metal welded on to chromium-nickel-molybdenum steel depends upon the quantity of ferrite in the structure and the conditions of heat treatment.

The best resistance was shown by steel samples after their tempering for austenite from 1065° C, or after stabilizing at 845° C. A heating of steel at a temperature of ~650° C considerably decreases the corrosion-resistance of welded joints. When particles of the α-phase and carbides are located along

Fig.46. Influence of molybdenum content of steel type 19-9 and 18-12 on corrosion-resistance in 65% boiling nitric acid and in an acidified solution of copper vitriol with sulphuric acid.

FIG. 46: Influence of molybdenum content of steel type 19-9 and 19-12 on corrosion-resistance in 65% boiling nitric acid and in an acidified solution of copper ~~xxxxxx~~ vitriol with sulphuric acid.

ordinate: rate of corrosion (mm/yr)

abscissa: % Mo

first curve to left: ~~steel~~ Steel Kh19N9

second curve from left: ~~[illegible]~~
$CuSO_4 + H_2SO_4$

third curve from left: Steel KH19M12 (65% HNO_3)

the surfaces of grains in the shape of highly dispersional unbroken formations, the welded joints have low corrosion resistance. (129)

Coagulation of α-particles increases the corrosion resistance of chrome-nickel-molybdenum steel.

According to article (129) it is better when the content of ferrite in the metal of welded seams somewhat exceeds 1-4 %.

In cases where the steel is intended for work at high temperatures, the generation of α-phase is undesirable. The best results are shown by a steel known as type 16-13-3, which has a smaller content of chrome and a heightened content of nickel. Adding titanium and niobium to chrome-nickel-molybdenum steel removes the tendency toward inter-crystallic corrosion, which appears as a result of heating at moderate temperatures. The tendency of this steel to the formation of α-phase increases with an increase of titanium and niobium contents (72)

For the welding of chrome-nickel-molybdenum steel 19-9-2.5, added with around 0.8 % Nb is used. In welded seams this steel has a sufficient quantity of ferrite which is very important for eliminating hot cracks.(54)

THE COMPOSITION AND PROPERTIES OF TYPE 23-13 (E1319) STEEL

This brand of steel has an increased resistance to oxidation at high temperatures (up to 900-1000° C). The steel is usually used for making high-temperature oxidation-resistant parts for furnace fittings. The mechanical properties of steel 23-13 are close to the properties of type 18-8 steel. Protracted heating at 650° - 750° C embrittles the steel in consequence of ferrite evolution, from which, in turn, -phase is developed. After 2,000 hours of heating at 600° C the impact strength of the steel drops from 21 to 0.8 - 1.6 kg/cm². (46)

CONTENT AND PROPERTIES OF CHROME-NICKEL STEELS OF TYPE 23-18, 25-20.

(E1417)

These steels have a comparatively stable austenitic structure, high resistance to corrosion by gas and satisfactory technological properties. It must be noted that this steel is somewhat harder to weld than are steels of type 18-8. The heat-enduring properties of these steels depend to a great extent upon grain size and upon the conditions of thermal treatment. The large grain in steel 25-20 imparts to it greater heat endurance, but lower plasticity. (45)

In practice this steel is used after tempering at from 1100° C and cooling in water or oil.

Steel 23-18 is used widely as a high-temperature oxidation-resistant material for heated pipes and jet apparatuses. Steel 23-18 with a carbon content above 0.05% and with large grain acquires a tendency toward inter-crystalline corrosion after being heated at temperatures of 600-800° C, and disintegrates when affected by highly aggressive mediums. (84) Heating to higher temperatures does not cause this phenomenon.

COMPOSITION AND PROPERTIES OF CHROME-NICKEL STEEL OF TYPE 25-20 WITH ADDITIONS OF 2.5% Si.

These steels have still greater resistance to oxidation at high temperatures, and especially, in at atmosphere of combustion products of fuels with an increased sulphur content. In de-oxidizing mediums this steel has a higher resistance again st (************) in comparison with commonly-used chrome-nickel steels. The addition of silicon, however, increases the tendency toward evolution of the σ-phase during protracted heating which, as is natural, lowers somewhat the plasticity of the steel. Repeated heating to temperatures of σ-phase dissolution eliminates brittleness.

CHROME-NICKEL STEEL 18-25 WITH ADDITION OF 2 % Si (Kh18N25S2)

Steel 18-25 to which silicon has been added is used as a heat-resistant material for making stressed parts, working at temperatures up to 1,000° C. (furnace and boiler fittings). In connection with a high nickel content the steel is insufficiently resistant to corrosion by gas in combustion products of fuel with an increased sulphur content. (15),(2),(22). The steel acquires a tendency toward inter-crystalline corrosion after protracted, repeated heating at 600-800° C. Heat-enduring properties of the steel are satisfactory up to temperatures of (*******) -- 750° C. The plasticity of steel Kh18N25S2 is low. (46)

COMPOSITION AND PROPERTIES OF STEEL Kh20N14S2

This steel has a high resistance to corrosion by gas. It is used in making parts of ovens and furnace fittings . In its heat-enduring properties this steel is close to steel of type 18-8, but has lower plasticity. (46)

THE COMPOSITION AND PROPERTIES OF CHROME-NICKEL STEEL OF TYPE 14-14 WITH AN ADDITION OF TUNGSTEN AND MOLYBDENUM

Steel 1Kh14N14V2M (EI257) This steel was intended for making high-pressure boilers working at temperatures up to 600° C. Its heat-enduring

properties are superior to steel of type 18-8 with titanium and niobium and is close to steel of type 18-12 with 3% Mo.

An essential defect of steel 1Kh14N14V2M is its tendency toward inter-crystalline corrosion. Cases of rapid decomposition as a consequence of inter-crystalline corrosion have been noted in working conditions of high-pressure boiler installations.

At the present time this steel is replaced by steel EI257T, which has no tendency toward inter-crystalline corrosion and is distinguished by a sufficiently high heat-endurance. (131)

CONTENT AND COMPOSITION OF CHROME-NICKEL-COPPER-MOLYBDENUM ACID-RESISTANT STEELS

These steels usually have an increased content of nickel with 8 or 16% Cr. These steels came into especially widespread use after the war. Table 1 gives the chemical content of steels that are corrosion-resistant in sulphuric and hydrochloric acids. (9),(13),(14).

Steels of type 18-25-4Mo-3Cu show high corrosion-resistance at room and heightened temperatures. The loss of weight at 105° C in 20% solution of sulphuric acid does not exceed 1 g/m^2 per hour. This magnitude re-calculated into the depth of corrosion is equivalent to a metal loss of 1 mm/year.

At temperature below 60°C the depth of corrosion does not exceed 0.1 mm/yr.

Fig. 47 shows changes in the corrosion-resistance of three steels of this type in sulphuric acid, at 80 and 100°C, depending upon the concentration of the acid (9).

Chrome-nickel-molybdenum steels belong to the austenitic class and possess high properties of toughness and plasticity (see table 2).

Properties of toughness may be improved by cold plastic deformation of the steels. Cold deformation changes only slightly the corrosion-resistance of steel 18-28-4 Mo (*****) in sulphuric acid of different concentrations (5, 10, and 20%. This shows the possibility of making parts by cold deformation, and of simultaneously increasing the toughness of the steel welds well, but welded joints notwithstanding very small carbon content and even additions of titanium sometimes acquire a tendency toward inter-crystalline corrosion. Therefore, items made of steels EI533 and EI530 must be subjected to thermal treatment after welding, or to quick cooling during welding (13).

Steels of type 0-35-4-4-4 and 8-32-4-4-4 investigated by the author of this article, deserve special notice (see steels no. ******* and 17 in table 1.) Without chrome or with a low chromium content (8%) they have no inclination

toward inter-crystalline corrosion, and are highly resistant to corrosion in sulphuric acid diluted 5 - 90% at temperature up to 80 - 100°C. It must be noted that a higher corrosion resistance in sulphuric acid is shown by alloys based on nickel with molybdenum and silicon (Hastalloy B *****) (110), (111), (112), (114), and ferrolite (10), (56), and (65). Alloys ferrosilic with molybdenum (MF15) and Hastalloy B also have high resistence in hydrochloric acid. (fig. *****).

Fig. 47. The influence of sulphuric acid concentration upon corrosion resistance of steels E1530, E1533 and E1629.

A) (upper parts of diagrams): At 100°C

b) (lower parts of diagrams) at 80°C

Curve 1: for 50 hours

2: for 100 hours

3: for 200 hours

Ordinate: g/m^2 per hour

Abscissa: Concentration of H_2SO_4 by %

Fig. 48. Corrosion resistance of alloys Hastalloy B and C in sulphuric and hydrochloric acids of different strengths

Ordinates: Rate of corrosion, in mm per year.

Abscissa: (first and second): Concentration of H_2SO_4.

(third): Concentration of HCl.

Legends: upper: 1) Alloy B, 2) Alloy C, 3) C

lower: 1), 2) and 3) Boiling acid

Table 10. Chemical composition of corrosion-resistant chrome-nickel steels with additions of copper, molybdenum and silicon.

1) Brand, 2) Average chemical composition, in %, 3) other elements

No.	POR
1	AISI-316
2	AISI-317
3	DURIMET T
4	DURIMET 20
5	CLORIMET
6	WORTHITE
7	ALLOY
8	ALLOY Kh23N
9	ALLOY [illegible]
	ALLOY-MOLYBDENUM Mo
10	RESISTOL 2600
11	P-704 (V164)
12	Carpenter 20
13	18-18-4
14	18-18-4-2
15	18-18-2-2
16	0-35-4-4-4
17	8-32-4-4-4
18	17% Cr
19	18-8 c Ti
20	8-18-3 4 Mo-2, 1 Cu
21	18-12-3 Mo
22	18-[illegible]-3-2
23	18-2[illegible]-4-2
24	20-20-3-1

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H[illegible]DURING STEELS A[illegible])

A general qualification demanded fr[illegible] he[illegible]ing materials, is high resistance to deformation and destruction under [illegible]e simultaneous action of temperatures and stress. Moreover, heat-enduring materials must resist destruction by corrosion caused by the influence of hot, and sometimes aggressive gases.

Therefore, heat-enduring materials must be at the same time also high-temperature oxidation resistant.

The basic classes of heat-enduring steels and alloys (in the order of increasing heat-endurance) are:

1) Chrome-silicon and chrome-silicon-molybdenum steels of the perlite class (silchromes);

2) Highly chromous steels of semi-ferritic and ferritic classes;

3) Chrome-nickel and chrome-manganese complexly alloyed steels of the austenitic class;

4) Alloys on the basis of nickel, titanium, cobalt, chrome and molybdenum.

CHROME-SILICON AND CHROME-SILICON-MOLYBDENUM STEELS OF THE PERLITE CLASS (SILCHROMES).

Silchromes are used mainly for making intake and exhaust valves of tractor and automobile engines (table 11).

The critical points of silchromes are very high; tempering temperatures range from 950 to 1100°C.

Annealing after tempering is done at 700-800°C to obtain a sorbitic structure with hardness of $H_{R_C} = 25 \div 35$.

Silchromes are very sensitive even to small fluctuations in the conditions of thermal treatment. This may cause considerable brittleness and, specifically, the breaking of valves at work. A high content of silicon and chrome increases the tendency toward brittleness from annealing (fig. 49). An addition of molybdenum somewhat decreases this brittleness and the tendency toward grain growth during heating.

A positive influence on decrease of brittleness of silchromes appears also on nickel and tungsten. The properties of silchromes during high temperature are illustrated in tables 12-15 and in fig. 50 and 51.

The alloying of valve steels simultaneously with chrome and silicon is done mainly to increase high-temperature oxidation resistance. The joint influence of chrome and silicon upon the increase of resistance to oxidation at high temperatures, is illustrated by the diagrams on fig. 52 and 53 (1). Because it is necessary to preserve a definite level of technological properties

Table 11. Chemical composition and approximate intended use of basic brands of valve steels (silchromes)

A) Temperature of the beginning of intensive oxidation, in °C

B) Approximate intended use

Valves for light machines and tractors of low power

Intake vales of light cars and trucks

Intake and exhaust valves of medium-power engines (or motors)

Valves of truck engines

Intake and exhaust valves of medium-powered aviation motors (with good cooling). Subjected to nitriding and weld-over with stellite.

Valves for high-powered engines. Has the utmost heat resistance in comparison with other brands of silchromes.

1) Steel
Kh6S (ESKh6)
Kh9S2 (ESKh8)
Kh6SM (ESKh6M)
Kh7SM
Kh10S2M (EI 107)
Kh13N7S2

2) Mn not over

3) Ni not over

Fig. 49. The influence of annealing temperature upon the resilience of silchromes (M. V. Pridantsev). After annealing: slow cooling with the furnace

Composition of silchromes:

1) 0.4% C, 2.26% Si, 9.07% Cr, 0.31% Mo.

2) 0.4% C, 2.75% Si, 8.44% Cr, 0.39% Mo.

3) 0.43% C, 2.73% Si, 10.21% Cr.

4) 0.41% C, 3.6% Si, 8.92% Cr.

Ordinate: kg/cm^2

Abscissa: Temperature $^{\circ}$C

Fig. 50. Resistance to creep of steel Kh10S2M (EI107)

Ordinate: Yield point, in kg/mm^2

Abscissa: Rate of creep, in % per hour

Fig. 51. Tensile strength of steel Kh10S2M (EI107).

Ordinate: Limit, in kg/mm^2

Abscissa: Time until destruction, in hours

Table 12: Mechanical Properties of Silchrome Mark Kh9S2 (Short Time Testing for Expansion)

1) Test temperatures in ^{o}C

2) Limit of durability (^{A}B in KG/MM^2)

3) Limit of proportionality (^{A}1 TS in KG/MM^2)

4) Expansion in %

5) Contraction in %

Table 13. Mechanical properties of silchrome of brand Kh10S2M (EI107) (Short-time tests for tensile strength. Thermal treatment of samples; tempering at from 1010-1050°C in oil, annealing at 750 ± 30°C, cooling in oil.)

1) Test temperature, in °C

2) Tensile strength, in kg/mm^2

3) Relative stretching, in %

4) Narrowing (contraction) of cross-section

Table 14. Resistance to creep of silchrome of brand Kh10S2M (EI107)

1) Test temperature, in ^{o}C
2) Stress (or strain), in kg/mm^2
3) Rate of creep, in % for 100 hours
4) General deformation, in mm/mm
5) Test temperature, in ^{o}C
6) Stress (or strain) in gk/mm^2
7) Rate of creep, in % for 100 hours
8) General deformation, in mm/mm

Table 15. Mechanical properties of steel Kh13N7S2 at increased temperatures.

(Short-time test for tensile strength)

1) Test temperature, in ^{o}C
2) Tensile strength, in kg/mm^2
3) Test temperature, in ^{o}C
4) Tensile strength, in kg/mm^2
5) Note: Annealing at $870^{o}C$ (during 5 hours); cooling at a rate of 100^{o} per hour, further cooling with the furnace

and, specifically, of deformability, the silicon content, as a rule, does not exceed 2.5-3%. It must be also kept in mind that, if with 6-8% of Cr the silicon content will exceed 3.5%, the steel will become ferritic and non-toughenable by methods of thermal treatment. This must be taken into account when processing chrome-silicon steels, the mechanical properties of which, in general, are not high.

The following steels are used (2) abroad for making valves:

1) Steel containing 0.6% C, 1.5% Si, 0.6% Mn, 6.0% CR, 0.5% Mo (average content). The steel has good resistance to creep at 450-650°C (table 16). However, it oxidizes comparatively quickly at temperatures above 700°C. It is used only for intake and exhaust valves of automobiles and for valves of low-powered aviation motor. After tempering at from 980°C in oil and annealing at 740°C, the steel, at 20°C, has the following properties: yield point of 70 kg/mm^2, elongation of 20%; narrowing of cross-section ψ of 40%.

2) Standard English valve steel for automobile engines: It has an average content of 0.45% C, 2.2% Si, 8.5% Cr. The yield point of this steel is below that of the steel mentioned above. However, it has an increased high-temperature oxidation resistance (at up to 800-850°C). Its thermal treatment:

Fig. 52. The influence of chromium and silicon content upon high-temperature oxidation resistance of iron in various atmospheres.

1) in air 2) in blast furnace gas 3) in illuminating gas

The lines on the diagram correspond to a high-temperature corrosion resistance of 1 gram per M^2 per hour, for 120 hours.

Fig. 53. The influence of chromium and silicon content upon high-temperature oxidation resistance of steel heated in air

1) 0.5 to 1% Si; 2) 2 to 3% Si

Ordinate: Loss of weight, in g/M^2 per hour, for 120 hours

Abscissa: Chromium content, in %

Table 16 Resistance to creep of valve steel (1.5 Si - 6 Cr - 0.9 Mo)

1) Test temperature, in °C

2) Stress (or strain) causing, in kg/mm^2

3) Creep of 1% for 300 hours

4) Rate of creep 10^{-5}% per hour

tempering in oil at from 1050°C, annealing at 850°C, cooling in oil or water for some decrease of brittleness from annealing. Its mechanical properties at 20°C are: σ = 90 kg/mm^2, δ 10 = 24%. In short-time tests for tensile strength at 600°C (with rate of deformation at 0.7 mm per minute) the steel had σ = 28.4 kg/mm^2. The coefficient of thermal expansion ($\times 10^{-6}$) was: within a temperature range of 20-200°C 12.6, of 20-400°C 12.9, of 20-600°C 13.4.

3) For valves working at 430-450°C, when a specific brittleness may appear in chrome-silicon steels, a nickel steel containing: 0.3% C, 0.25% Si, 3.25% Ni (average content) is recommended. The Thermal treatment of this steel is: tempering in oil at from 850°C, annealing at 600°C. The mechanical

properties at 20°C are: α_B = 82 kg/mm^2, α_T = 60 kg/mm^2, δ 10 = 22%, ψ = 65%; stress causing creep of 0.1% for 1000 hours at 427°C amounts to 8.6 kg/mm^2.

4) In England, (2) for making heavily loaded valves of aviation motors an austenitic steel is used, which contains on the average: 0.42% C, 1.5% Si, 13% Cr, 13% Ni, 2.5% W (corresponding approximately to steel EI69 or 4Kh14N14V2M). The thermal treatment includes normalization at from 950°C the mechanical properties at 20°C are: α_B = 83 kg/mm^2, δ_{10} = 31%; stress causing a creep rate of $10^{-6\%}$ per hour at 650°C is 12.6 kg/mm^2, at 700°C 6.9 kg/mm^2, at 750°C 4.7 kg/mm^2. The coefficient of thermal expansion (x 10^{-6}) is within temperature ranges: 20-200°C ... 17.3; 20-400°C ... 18.3; 20-600°C ... 18.9; 20-700°C ... 19.1; 20-800°C ... 19.2.

The necessity of improving the mechanical properties of valve steels demands a more complicated composition and also the use of austenite class steels for making valves. (Table 17) Especially effective for increasing toughness and heat-endurance of valve steels is alloying with cobalt (table 18). Besides, the use of a steel (4) containing around 8% CR, ~ 3% Mo and ~ 2% Ti with 0.2-0.4% C is reported. Toughening of this steel results from aging of the ferritic base, which generates carbides

Table 17. Composition and properties of valve steel used in German industry (?).

1) Chemical composition (average), in %

2) Mechanical properties

3) Notes or remarks

Small-load valves for fork at temperatures up to 650°C

Medium-load valves for work at temperatures up to 700°C

Heavy-load valves for work at temperatures up to 800°C

of type $M_{23}C_6$ and an intermetallic compound of type Fe_2Ni. Tests of heat-enduring properties show that the steel can be used not only for valves, but also in boilermaking for long service at temperatures up to 620°C. In making valves of chrome-silicon and chrome-silicon-molybdenum steels it must be taken into account that these materials have a tendency toward intensive decarbonization from the surface when heated to temperatures of their thermal treatments. This reduces hardness and causes the

appearance on surfaces of a large-grained boundaries, which causes brittleness.

Considering the peculiarities of valve making it must be born in mind, that valves made of silchrome must be securely bonded with stellite, which is welded-on to increase wearability and resistence to burn-offs on the plug and seat of the valve, and that the valve must be subjected to nitriding to increase the wear-resistance of the valve rod.

Table 18. The influence of cobalt upon the properties of valve steels at high temperatures

1) Chemical composition (average), in %

2) Limit of tensile strength in kg/mm^2 in short-time tests at temperatures in °C

The silchromes used in our country are satisfactorily weldable-over with stellite, forming a sufficiently solid bond with a somewhat coarse-grained martensitic structure, which may be improved by thermal treatment.

The nitrided layer of silchromes has no sharp transition to the base metal and shows no excessive brittleness (the structure of the layer consists of sorbite and nitrides).

Under conditions of service at high temperatures (400-800°C) a thermal brittleness appears in silchromes, which are steels of perlite class, as it also appears in some austenitic steels.

The decrease of resilience, which determines thermal brittleness, is sometimes accompanied by changes in plasticity and toughness. The basic factors, which determine the appearance and degree of thermal brittleness are temperature and duration of heating and also the chemical composition of the steel. The stress applied also exerts great influence.

HIGHLY CHROMOUS STEELS OF SEMI-FERRITIC AND FERRITIC CLASS

The chemical composition and the exemplary intended use of the fundamental brands of highly chromous steels utilized in our industry are given on pages 344-3460. Basically, steels containing around 12% Cr are used.

In steel 1Kh13 during heating polymorphic changes take place. This makes it possible to modify the properties of the steel to a comparatively great extent by applying different conditions of thermal treatment.

Stock for turbine vanes of steel 1Kh13 is usually subjected to tempering in oil at from 1000 to 1050°C and to annealing at 700-750°C. Annealing within a temperature range of 400-500°C may cause serious brittleness.

Characteristics of creep and of toughness of steel 1Kh13 after tempering at 1030-1050°C and annealing at 750°C are given in Fig. 54 and 55.

After tempering and annealing at 650-700°C the yield point with a stretch of 1% for 10,000 hours amounts to: at 540°C to 8.4 kg/mm^2, at 590 to 3.5, at 650 to 1.5, at 700 to 1.0 kg/mm^2.

Fig. 54. Resistance to creep of steel 1Kh13.

Ordinate: Yield point, in kg/mm^2

Abscissa: %/hour

Working conditions of steam turbine vanes (pulsing stroke of steam flow leaving the jet apparatuses) requires a high limit of fatigue in steels 1Kh13 and 2Kh13. As it follows from data in table 19, compiled according to results obtained by various investigators, the limit of fatigue after suitable thermal treatment amounts at room temperature to approximately half the magnitude of tensile strength.

Fig. 55. Tensile strength of steel 1Kh13.

Ordinate: Limit, in kg/mm^2

Abscisse: Hours

Legends from top to bottom: 1) (notched), 2) (calculated), 3) (smooth), 4) (notched), 5) (smooth)

The influence of work environment (steam or water) causes a lowering of the fatigue limit (corrosional fatigue), which is especially sharp when thermal treatment for toughness, for instance annealing, has been applied (table 20).

According to data given by I. V. Kudriavtsev, (29) processing with rollers (surface cold hardening) heightens considerably the fatigue limit of steel 1Kh13, especially noticeable in the testing of notched samples (fig. 56): Similar results are obtained in case of nitriding (fig. 57). The latter treatment causes an essential increase of wear-resistance

Fig. 56. Changes in the fatigue limit of steel 1Kh13 in dependence upon test temperature (base 10^7).

1) smooth rolled,
2) smooth,
3) notched,
4) rolled and notched

Ordinate: Limit, in kg/mm^2

Abscissa: Temperature, $^\circ$C

Fig. 57. Changes in the fatigue limit of nitrides (1) and not nitrided (2) smooth samples of steel 1Kh13 in dependence upon temperature of test (base 10^7 Cycles).

Ordinate: Limit, in kg/mm^2

Abscissa: Temperature, $^\circ$C

The influence of variation in the number of cycles upon fatigue resistance is shown in table 21.

Table 19. Resistance to fatigue of some highly chromous steels

1) Composition of steel in % or: content of steel, in %, of

2) Treatment

Tempering at 930°C, annealing at 480°C

Same with different figures

Last line: After rolling

3) Yield strength, δ_{T} kg/mm^2

4) Fatigue limit, δ^{-1} kg/mm^2

Table 29. Characteristics of corrosional fatigue of highly chromous steel (0.12% C, 12.5% Cr)

1) Medium in which testing was done

Air at room temperature

Exhaust steam

Steam and air in a vessel at 75°C

Steam at atmospheric pressure and 100°C

Steam under pressure of 43.6 atm. at 150°C

Steam under pressure of 112 atm. at 180°C

Steam under pressure of 160 atm. at 370°C

Corrosion during one week in moist steam mixed with air of room temperature

2) Fatigue Limit in kg/mm^2

3) Remarks: Properties after tempering and annealing at high temperature:

Table 2[illegible]. Changes in fatigue limit of steel 1Kh13 in dependence upon the basis of tests

1) Test temperature, in °C

2) Fatigue limit, in kg/mm^2

3) Smooth samples

4) Basis 10^7 cycles

5) Basis 4×10^7 cycles

6) Notched samples

7) Basis 10^7 cycles

8) Basis 5×10^7 cycles

The most important technological property of steel 1Kh13 is its satisfactory weldability. After welding a thermal treatment is necessary according to specifications: heating to 760-780°C during 2 hours, slow cooling.

Steel 2Kh13 also is tempered at temperatures from 1000-1050°C with cooling in oil or is normalized from the same temperatures. The final operation is annealing at 660-770°C. The application of higher tempera-

tures is not rational, because it causes considerable grain-growth and produces brittleness.

Fig. 58. Influence of treatment duration upon mechanical properties of steel 2Zh13

Ordinate: (somewhat illegible)

Abscissa: hours

Therefore, if in consequence of the tempering of some smelting batches of steel 2Zh13 (having a chrome and carbon content of the upper limit) a part of the carbides is conserved, no repeated tempering at higher temperatures should be done. The influence of heating duration upon the mechanical properties of type 2Zh13 steel at 20°C is shown in fig. 58. The results of short-time tests for tensile strength at high temperatures are given in fig. 59 (treatment: normalization at 1000-1020°C, annealing at 720-750°C).

Fig. 59. Mechanical properties of steel 2Kh13. Short-time tests for tensile strength

Ordinate: (somewhat illegible)

Abscissa: Temperature, °C

Fig. 60. Resistance to creep of steel 2Kh13.

Ordinate: Limit, in kg/mm^2

Abscissa: % per hour

The limits of toughness and creep of steel 2Kh13 at temperatures of 450-550°C are given in fig. 60 and 61.

Steels 3Kh13 and 4Kh13, because of considerable carbon content, are capable of acquiring after temper[illegible] hardness with a heightened corrosion resistance. These properties determine the basic use of these steels as a material for items (among them tools) intended to work with wear in aggressive mediums. The necessity of accomplishing the dissolution of a considerable quantity of carbides makes it expedient to increase tempering temperature to 1050-1100°C. During this no considerable grain-

growth is observed because of the influence of excessive carbides. High hardness ($H_{R_C} = 45 \div 50$) is conserved after lowering temperature to 200-300°C. The influence of the duration of heating upon mechanical properties at 20°C of steel 3Kh13 normalized from 1000°C and annealed at 650°C is given in fig. 62.

Fig. 61. Tensile strength of steel 2Kh13.

Ordinate: Limit, in kg/mm²

Abscissa: Hours

Because of unstable structures produced in consequence of thermal treatment, steels 3Kh13 and 4Kh13 are almost never used for articles intended for long service at high temperatures. Even steel 3Kh13 containing less carbon than steel 4Kh13, shows after tempering in oil at from 980°C and annealing at 675°C, a very quick loss of toughness at temperatures above 300°C.

Fig. 62. The influence of the duration of heating at 500, 550 and 600°C upon mechanical properties of steel of type 3Kh13 at room temperature. Treatment: normalizing from 1000°C, annealing at 650°C.

Ordinate: not too clear

Abscissa: Hours

So, the yield point with a stretch of 1% per year (8760 hours) at 20°C amounts to 55 kg/mm², at 150°C to 51.5 kg/mm², at 200°C to 51.5 kg/mm², at 650°C to 0.91 kg/mm², at 785°C to 0.32 kg/mm².

Short-time tests for tensile strength also show a steady and intensive lowering of toughness in proportion to increasing temperature (fig. 63).

Steels Kh17, Kh25 and Kh28 are used, in an overwhelming majority of cases, as corrosion-resistant materials because they have very low toughness at high temperatures (fig. 64, 65). The main defect in the steels of these brands is their high brittleness and low technological

properties - deformability and weldability. Being practically single-phased, steels with 17-30% Cr are very inclined toward grain-growth when heated, which leads to a sharp decline of tensile strength.

Fig. 63. Changes in the mechanical properties of steel 3Kh13 with increasing temperatures of tests for tensile strength. Treatment: normalizing from 1000°C, annealing at 650°C

Abscissa: Temperature, °C

Fig. 64. Results of short-time tests for tensile strength of steel Kh17 at heightened temperatures (Kulygin). At temperatures of 700-1200°C the sample tested for resilience by impact did not break (curve a_n)

Abscissa: °C

Fig. 65. Results of short-time tests for tensile strength of type Kh25 steel at heightened temperatures (Kulygin). At temperatures of 800-1200°C the sample tested for resilience (impact strength) did not break.

Abscissa: °C

The technological properties in steels of these brands may be improved by additional alloying with nitrogen and also with nickel, copper and titanium.

During recent years a number of investigations were made, the purpose of which was to improve the properties of highly chromous steels at heightened temperatures. The attention given to steels of this type, notwithstanding the existence of more heat-resistant austenitic steels, is explainable, first by the comparative inexpensiveness of chromous steels and secondly by lesser warping during the work of items made of

them, in consequence of better heat-conductivity and a smaller coefficient of thermal expansion.

Fig. 66. Tensile strength of steel EI800 at 560°C

Ordinate: Limit, in kg/mm²

Abscissa: Hours

Fig. 67. Tensile strength of steel EI802

Ordinate: Limit, in kg/mm²

Abscissa: Hours

The following brands of complexly alloyed chromium steels have found application in national industry:

Steel EI800, containing: 0.1-0.17% C, ≤ 0.5% Si, 0.8-1.3% Mn, 10-12% Cr, 0.6-0.8% Mo, 0.2-0.4% V, 0.4-0.7% Nb, 0.5-1.0% Ni. The mechanical properties of the steel are given in table 22, while data concerning toughness at 560°C are given in fig. 66.

Steel EI802: 0.11-0.18% C, 0.17-0.37% Si, 0.6-1.0% Mn, 11-13% Cr, 0.5-1.0% Ni, 0.7-1.0% W, 0.4-0.6% Mo, 0.15-0.3% V. The steel is subjected either to tempering in oil or to normalizing at from 1000 to 1050°C and a final annealing at 680-700°C during 2-10 hours. Data concerning toughness are given in fig. 67. The steel is used at temperatures up to 580°C.

Table 22. Mechanical properties of steel EI800 (in short-time tests of expansion)

1) Properties of steel

2) Limit of durability δ_{T} in kg/mm^2

Limit of flow δ_{T} in kg/mm^2

Lenghtening δ_5 in %

Cross-section of contraction ψ in %

Shock toughness α_{μ} in kgm/cm^2

3) Temperature of tests in °C

Steel EI756: 0.1-0.15% C, 10.5-12.5% Cr, 1.8-2.2% W, 0.6-0.8% Mo, 0.2-0.3% V, 0.2-0.35% Si, 0.6-0.8% Mn.

Steel EI757: 0.1-0.15% C, 10.5-12.5% Cr, 3.7-4.3% W, 0.6-0.8% Mo, 0.2-0.3% V, 0.2-0.35% Si, 0.6-0.8% Mn. The results of testing steels EI756 and EI757 for toughness at 600°C are given in fig. 68 (10).

At the Leningrad Metal Works it was established (11) that steels with 12% Cr and additions of 0.6% Mo + 0.3% V and 1% W + 0.3 V have the highest heat endurance, high stability of structure, and low sensibility to stress concentrations, which makes it possible to recommend them as materials for long-life turbine vanes and other parts, working at temperatures of up to 550-560°C. At 550°C the stipulated yield point of these steels corresponding to a creep speed of 10^{-5}% per hour is equal to 8.5-9.5 kg/mm^2. (The upper limit corresponds to steel with 0.6% Mo + 0.3% V.)

Fig. 68. Continued durability of steel EI757 (curve 1) and EI756 (Curve 2) at 600°C

12% chromium steels with additions of molybdenum or molybdenum with vanadium and niobium are used also abroad (fig. 69).

The alloying of highly chromous steel with aluminum or aluminum and molybdenum causes a substantial change in steel structure.

Fig. 69. Limits of tensile strength of some complexly alloyed 12% chrome steels in a test duration of 1000 hours.

Ordinate: Limit in kg/mm^2

Abscissa: $^{\circ}C$

Fig. 70. The influence of aluminum and molybdenum upon resistance to creep and tensile strength of 12% chrome steel, containing:

Curve 1: 0.15% C, 11.5% - 13.5% Cr,
2: 0.15% C, 11.5 - 13.5% Cr, 0.1 - 0.3% Al, 0.5% Mo

Ordinate: Limits of strength, of creep, in kg/mm^2

Abscissa: $^{\circ}C$

Markings at curves: upper: limit of strength
lower: limit of creep

Therefore, if steel containing 0.15% C and 11.5 - 13.5% Cr is temperable for martensite after cooling in oil from temperatures of 1000-1050°C, the alloying of this steel with 0.1 - 0.3% Al or 0.1 - 0.3% Al and 0.5% Mo causes a purely ferritic structure, and the steel has no transmutations within the whole range of temperatures from room temperature to that of melting point. Such a stable structure of highly alloyed chrome-molybdenum-aluminum ferrite, secures heightened corrosion-resistance and also better heat endurance at temperatures up to 500°C when no intensive re-crystallization is observed. Data concerning resistance to creep are given in fig. 79.

It should be especially noted that steel of the type mentioned has a very low coefficient of thermal expansion ($\alpha \cdot 10^6$), which is equal within temperature ranges as follows: from 20 to 100°C 9.3; 20 - 200°C 10.9; 20 - 300°C 11.3; 20 - 400°C 11.5; 20 - 500°C 12.0; 20 - 600°C 12.1.

During investigation of the structure and properties of steel with 12% Cr modified with various additions, it was established (12) that

1) additions of niobium increase toughness and resistance to creep,

2) additions of titanium lower heat resistance considerably,

3) molybdenum increases toughness and resistance to creep,

4) an increase of carbon content from 0.17 to 0.23% lowers resistance to creep.

Besides, there are reports of the use of cast 12% chrome steel of the following brands: (The contents given are of batches investigated):

12Nb: 0.15% C, 0.49% Mo, 11.3% Cr, 0.49% Mn, 0.08% Si, 0.7% V, 0.14% Nb.

12V: 0.16% C, 0.55% Mo, 11.5% Cr, 0.5% Mn, 0.18% Si, 0.68% V.

12Mo: 0.17% C, 1.01% Mo, 11.3% Cr, 0.49% Mn, 0.15% Si, 0.69% V.

The tensile strength of these steels at 650°C is given in table 23.

Table 23. Tensile strength of cast 12% Chromous steel of some brands at 650°C

1) Brand of steel

2) State (or condition) of samples

(a) Cast
After thermal treatment

(b) Cast
After thermal treatment

(c) Cast
After thermal treatment

3) Limit of tensile strength, in kg/mm^2

4) Relative elongation at breaking moment, in %

5) Time in hours

It must be noted that cast 12% highly chromous steels with additions of 2.5% of molybdenum, 0.5% of vanadium, 1.5% of tungsten and 0.4% of titanium have found use in the making of such stressed parts of automobile gas turbines as working vanes and discs. A further improvement of the composition of steels has lead to an addition of 0.01 - 0.04% of boron. This addition proved to be so effective for increasing heat-resistance at 600-650°C that it became possible to forgo the alloying with vanadium (13). Case ferritic ferro-aluminum alloys containing up to 16% Al are also used in automobile gas-turbine engines.

These alloys have a high resistance to corrosion by gases but a small heat resistance. They are used for making case bodies of oil spray burners, directing vanes and similar parts working at high temperatures but under small stresses.

Alloying with nickel is widely used for improving heat-resistance of highly chromous steels.

Thus, if only 1.5-2% Ni is added to steel of type Kh27, the resistance to creep increases more than 1.5 times (table 24).

The addition of nickel to cast highly chromous steels proved to be especially effective. The characteristics of creep and tensile strength of such steels are given in table 25.

Table 24. The influence of nickel upon the resistance to creep of highly chromous type Kh27 steel that is being deformed

1) Test temperature, in ^{o}C; 2) Stress in kg/mm^2 that causes;

3) in steel Kh27 (a) 1% of elongation in 10,000 hours,
(b) destruction in 1000 hours;

4) in steel Kh27 plus 1.75% Ni (a) 1% of elongation in 10,000 hours,
(b) 1% of elongation in 100,000 hours.

Table 25. The influence of nickel upon resistance to creep and tensile strength of cast highly chromous steel of type Kh27

1) Composition of steel in %; 2) Stress in kg/mm^2 causing a speed of creep of 10^{-4}% per hour at temperature in ^{o}C;
3) Tensile strength in kg/mm^2 at temperature in ^{o}C; 4) hours.

It must be especially noted that in connection with the alloying of highly chromous steels with various elements, including such austenite-forming elements as nickel, many brands of austenite-ferrite steels have come into use.

Austenite-ferrite steels have greater heat-resistance than highly chromous ferrite and semi-ferrite steels. The basic qualification required of austenite-ferrite steels is stability of structure. Changes in the properties of some austenite-ferrite steels at room temperature in dependence upon their structure are shown in fig. 71. Their tensile strength at 600°C is given in fig. 72.

Considerable brittleness, called brittleness at 475°C, develops in highly chromous steels of the ferrite and austenite-ferrite classes with a heating to 450-500°C. This brittleness practically precludes the use of these materials for making stressed parts. The usual microscopic examinations do not offer any possibility of detecting the cause of the appearance of this great brittleness, and, thus, of pointing out a way toward its elimination.

Earlier it was supposed that the embrittlement of highly chromous steels at ~ 500°C was connected with an evolution of σ-phase, which usually develops at 700-800°C. It is known to generate in alloys containing over 30%

Cr during heating to a temperature range of 700-800°C. But investigations have shown (13), (15), (16) that the processes of embrittlement at ~ 500°C and at 700-800°C are independent of each other. This is corraborated by date given in fig. 73 and in table 26. Thus, the cause of brittleness at ~ 500°C is evidently conditioned by something different from σ-phase development, which was considered to be the cause before.

It was sh..n in work (17), that brittleness in highly chromous ferrite steel at 475°C is not only connected with the appearance of a second phase, as was commonly believed earlier, but also with a possible process of arrangement regulation within the hard solution.

Fig. 71. Properties of chrome-nickel steels with different structure.

Ordinate: Limits of creep and of , in kg/mm²

Abscissa: Content of nickel, in %

Ф (F) - ferrite,
M - Martensite,
A - austenite

Fig. 72. Tensile strength in steel of type Kh28 with different carbon and nickel contents at 600°C (according to VDE).

Ordinate: Limit of strength, in kg/mm²

Abscissa: Quantity of austenite in the structure, in %.

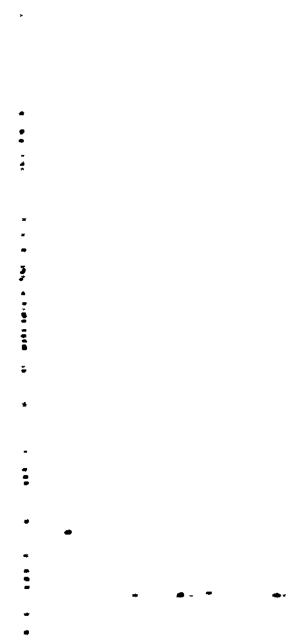

Fig. 73. The influence of temperature and duration of heating upon the hardness of chromous steel containing 18-50% Cr.

Ordinate: Hardness H

Abscissa: °C

Legends, from top: 1) Heating duration 100 hours,
2) Heating duration 1000 hours.

The same conclusion was reached by Baerleken and Fabrizius, (18) who investigated the influence of heating duration at 475°C upon magnetic properties of ferro-chromous steels containing 23.3-66% Cr.

The complicated character of transformation in highly chromous alloys was also established in the recent work of Pomey and Bastien (31). Alloys of great purity containing from 19.08 to 75.8% of chrome were studied. It was found, that in alloys containing 50% Cr three different processes may proceed

without a change of concentration, or more precisely, without diffusion to considerable distances:

a) magnetic transformation at the temperature of Curie point;

b) transformation in α -hard solution, connected with the process of arrangement $\rightleftarrows$ disarrangement;

c) phasic transformation $\alpha \rightleftarrows \sigma$.

Table 26. Mechanical properties of steel 1Kh18N9 at heightened temperatures

1) test temperature, in °C.

2) Limit of creep in kg/mm^2 with a speed of creep

a) of 0.1% for 1000 hours,

b) of 0.01% for 100 hours.

3) Elongation at rupture moment (in short-time tests) in %.

CHROME-NICKEL AND CHROME-MANGANESE COMPLEXLY ALLOYED STEELS OF THE AUSTENITIC CLASS

A characteristic peculiarity of these steels is the stability of austenitic structure, strengthened by dispersing emissions of different phases at high temperatures. In the majority of austenitic heat-resistant steels such a structure is produced by special thermal treatment.

The thermal treatment of heat-resistent steels of the austenitic class is based on the process of aging oversaturated hard solutions in connection with the formation of carbides, carbon-nitrides and intermetallic compounds.

Ageability is determined by variable solubility of the second component B in the hard solution γ (fig. 74). The whole quantity of component B contained in the alloy is dissolved in the hard solution during heating to tempering temperature. Then this condition is fixed by quick cooling.

The processes that will proceed in the oversaturated hard solution will be those connected with transition to a firmer, more stable state. These are the processes of aging.

The following mechanism of the process may be presumed: at the beginning, within the framework of the oversaturated hard solution, an accumulation of B atoms takes place in definite areas of the crystal lattice. The second stage of the process is the formation of a new crystal lattice which is specifically natural to the phase that develops. However, the lattice of the phase remains crystallographically close to the lattice of the hard solution. (A so-called coherent connection of lattices is observed.) The third stage is the breaking away of the lattices from each other and the formation of independent, very dispersive particles of the phase (or phase particles). The fourth stage is the enlargement (coagulation) of phase particles.

All the stages enumerated proceed in time and with temperature and sometimes coincide. The higher the temperature of aging, the shorter the heating duration must be to attain the objective assigned to a stage.

The process of aging is characterized by changes in hardness and toughness. The coherent connection of two different lattices, and, also the fall-out of very dispersive second-phase particles leads to a sharply increased resistance to plastic deformation and to an increase of hardness. However, if the first three stages of the process lead to toughening of the alloy (to a so-called dispersive hardening), then the fourth stage (coagulation of dispersive particles) is connected with a drop in hardness. (Fig. 75).

Fig. 74. Schematic diagram of the state of alloys inclined toward dispersional (or dispersive) hardening.

Ordinate: °C, temperature of tempering

Abscissor: % of

Fig. 75. Change of/in hardness (dispersion hardening) in aging alloys.

Ordinate: Hardness

Abscissor: Time or temperature

COMPOSITION AND PROPERTIES OF HEAT-RESISTANT STEELS OF THE AUSTENITIC CLASS

The properties of austenitic steels of type 18-8 at heightened temperatures may be characterized by data give in fig. 76-81 and in table 26.

Fig. 76. Limits of creep and strength in steel of type 0Kh18N9

1 - tensile strength for 1000 hours;
2 - tensile strength for 10,000 hours;
3 - speed of creep 10^{-6}% per hour;
4 - speed of creep 10^{-7}% per hour.

Ordinate: Limit of strength, of creep in kg/mm^2

Abscissa: °C

Fig. 77. Influence of test temperature upon the mechanical properties of type 1Kh18N9 steel

Ordinate: Limit of , of creep in kg/mm^2, δ 5, ψ , in %, resilience, in kg/cm^2.

Abscissa: °C

With an increase of the extent of alloying the service characteristics of austenitic steels also increase. This is connected both with the toughening of the basic hard austenite solution with a slowing down of diffusion processes

in it and with an improvement of structural stability. The latter is especially important because steel of type 18-8 is nearly on the border of the two-phase (or double phased) zone, and because, with deep cooling, a martensitic transformation takes place in the steel, as is shown by the curves in fig. 77. The beneficial influence of titanium is especially conspicuously illustrated by data of fig. 82.

Fig. 78. Limits of tensile strength of steel 1Kh18N9T

a) heating to 1050-1100°C, cooling in air, annealing at 700°C during 20 h.
b) heating to 1050-1100°C, cooling in air.

Ordinate: Limit of strength, in kg/mm^2

Abscissa: hours

An increase of carbon content in type 18-8 steel must be considered irrational because it increases brittleness of the steel in consequence of heating to high temperatures (fig. 83) when carbides are intensively evolved during a long period of time.

Fig. 79. Limit of creep in steel 1Kh18N9T: 1 - tempering at from 1150°C in water (translation literal, cooling in water is probably meant); 2 - tempering at 1050°C, air.

Ordinate: Limit of creep, in kg/mm^2

Abscissa: Rate of creep, % per hour

Fig. 80. Limits of creep and strength in steel of type Kh18N11B: 1 - tensile strength for 1000 hours; 2 - tensile strength for 10,000 hours; 3 - rate of creep 10^{-6}% per hour; 4 - speed of creep 10^{-7}% per hour.

Ordinate: Limit of creep, of strength, in kg/mm^2

Abscissa: °C

In order to economize on molybdenum, a chrome-nickel austenitic steel alloyed with tungsten was proposed. The yield point, causing an elongation of 10^{-6} per hour for steel containing 0.35% C, 1.8% Si, 8.0% Ni, 18.0% Cr and 3.5%, (illegible) at 550°C is 13.3 kg/mm^2, at 600 - 7.1, at 650 - 4.4, at 700 - 3.6, at 750°C - 2.8 kg/mm^2.

Further improvement of heat-enduring properties of austenitic type 18-8 steels, in connection with their complex alloying with some elements and also with an increase in the content of the basic elements - chromium and nickel.

Fig. 81. Limits of creep and strength in type Х18Н12М2Т steel. 1 - Tensile strength for 1000 hours; 2 - tensile strength for 10,000 hours; 3 - limit of creep with a speed of 10^{-6}% per hour; 4 - with a speed of creep 10^{-7}% per hour.

Ordinate: Limits of creep, of strength, in kg/mm^2

Abscissa: °C

Fig. 82. The influence of titanium upon steel of type 18-8 at high temperatures of short-time tests for extension.
1 - steel with 18% Cr, 8% Ni plus Ti;
2 - steel with 18% Cr, 8% Ni.

Ordinate: Limit of creep, of , in kg/mm^2

Abscissa: °C

Fig. 83. Embrittlement of type 18-8 steel with different contents of carbon in consequence of prolonged heatings at high temperatures

1 - steel with 0.06% C, 9.2% Ni, 18% Cr, tempering at from 985°C, cooling in water;

2 - steel with 0.13% C, 0.0% Ni, 18.2% Cr, tempering at from 1150°C, cooling in water;

3 - steel with 0.18% C, 8.9% Ni, 17.8% Cr, tempering at from 1150°C, cooling in water. Ordinate: , in kg/mm^2 Abscissa: hours

In considering this group of austenitic heat-resistant steels we shall dwell on the following brands:

Chrome-nickel-molybdenum steel of type 18-14-2-1 contains: 0.12% C, 0.9-1.5% Mn, 0.7-1.2% Si, 160-19% Cr, 140-17.0% Ni, 2.0-2.6% Mo, 0.9-1.3% Nb. The thermal treatment consists of tempering at from 1100-1150°C in water. Mechanical properties at heightened temperatures are given in table 27.

Table 27. Limits of tensile strength and creep in steel of type 18-14-2-1

1) Test temperature in °C

2) Limit of tensile strength in kg/mm^2 with a test duration in hours

3) Limit of creep with σ-creep of 1% for 300 hours, in kg/mm^2

Steel EI572 contains: 0.28-0.35% C, 0.3-0.8% Si, 0.75-1.5% Mn, 1.0-1.5% W, 18-20% Cr, 8-10% Ni, 1-1.5% Mo. 0.5-0.8% Nb, 0.2-0.5% Ti. Three variants of thermal treatment are recommended: 1) Tempering at 1150-1180°C, cooling in water, aging at 800°C during 15 hours.

2) Tempering at 1150-1180°C, cooling in water, aging at 750°C during [illegible]-15 hours.

3) Tempering at 1150-1180°C, cooling in water, aging at 700°C during 15 hours.

The characteristics of creep and of tensile strength of steel EI572 are given in fig. 84 and 85. The steel is used in building piped boilers at working temperatures of up to 600°C, more seldom of up to 650°C, because at the latter temperature and especially at 700-800°C a formation of σ-phase and of embrittlement connected with it is observed.

Steel EI694 is used for making pipe-lines in contemporary boiler installations. The steel contains: 0.07-0.12% C, $\leqslant$ 0.6% Si, 1-2% Mn, 13-15% Cr, 14-17% Ni, 0.9-1.3% Nb. Thermal treatment: tempering at from 1140-1160°C with cooling in water. Data concerning tensile strength and creep (fig. 86) show that pipes made of this steel may be used at temperatures of 600-610°C.

Steel EI695 is a modification of EI694. A great heat-resistance is achieved in it through an increase of nickel content and additional alloying with tungsten. The composition of the steel: 0.7-0.12% C, $\leqslant$ 0. [illegible]% Si, 1-2% Mn, 13-15% Cr, 18-20% Ni, 2-2.75% W, 0.9-1.3% Nb. Tempering is at from 1140-1160°C, cooling in water. The limits of tensile strength and creep are given in fig. 87. Pipes made of this steel can work at 650-700°C.

Fig. 84. Limit of creep in steel EI572: a) at 560°C; b) at 650°C

Ordinate: limit of creep Abscissa: rate of creep, in % per hour.

Fig. 85. Limits of tensile strength in steel EI572:

a) at 560°C b) at 650°C c) at 700°C

Ordinate: limit of strength, in kg/mm^2

Abscissa: hours

Some above-mentioned brands of austenitic chrome-nickel steel of type 18-8 contain around 1% of niobium. Sometimes together with niobium, tantalum is added to a total of around 1%. The addition of niobium to steel of type 18-8 not only improves its corrosion resistance, but also imparts to steel higher heat endurance under conditions of cyclic temperature routines. Such a beneficial influence of niobium was established in the work of Baldwin (20) during testing of type 18-8 steel with cyclic temperature changes from 200 to 700°C and with fluctuations of time periods at maximum and minimum temperatures from 6 to 12 hours.

For many years already work has been conducted in the field of replacing nickel by manganese in steels of type 18-8. During the process of such investigations and also in consequence of semi-industrial tests it was established, that, although manganese is analogous to nickel, the manganese austentic is less stable than that of nickel. After prolonged heatings at high temperatures the manganese austenite decomposes with a formation of α-phase. In order to obtain a stable austenitic structure with the replacement of nickel by manganese, such a strong austenite-forming element such as nitrogen must be supplementarily added to the steel composition.

Fig. 86. Limit of tensile strength for 100,000 hours and limit of 1% of creep for 100,000 hours in steel EI694 at different temperatures.

Ordinate: limit of creep, of strength, in kg/mm^2

Abscissa: $^{\circ}C$

Fig. 87. Limits of tensile strength for 100,000 hours and of 1% of creep for 100,000 hours in steel EI695 at different temperatures.

Ordinate: limit of strength, kg/mm^2

Abscissa: $^{\circ}C$

There are reports of introductions into industry (2) of a steel containing $\sim$ 0.1% C, $\sim$14.5% Mn, $\sim$17.5% Cr, $\sim$0.4% N_2. A test for extension at room temperature has shown that in the annealed state the steel has a tensile strength of 95 kg/mm^2, a yield point of 64 kg/mm^2 and an elongation of 40%. The mechanical properties of this chrome-manganese steel subjected to cold plastic deformation with a rolling shrinkage of 5% are close to the mechanical properties of chrome-nickel steel of type 18-8 subjected to cold plastic deformation with a rolling shrinkage of 25%.

With a deformation extent equal to 35% the steel has a yield point of around 130 kg/mm^2 with an elongation of 6%. A test for extension at heightened temperatures carried out on standard samples 12.8 mm in diameter has shown, that

up to 760°C the tensile strength and yield point in the new steel are higher than those of rust-proof type 18-8 steel of all other brands. The magnitude of extension and contraction of cross-section at test temperatures up to 540°C is of the same order as that in other steels of type 18-8, while at higher temperatures it drops sharply. The corrosion resistence of samples of this steel was studied in boiling 65% solution of nitric acid, in boiling 5% nitric acid and at 30°C in a 5% solution of sulphuric acid. From the tests carried out it is possible to conclude that the corrosion resistance of chrome-manganese steel is close to that of steels of type Kh17 and Kh16N1G17.

The austenite in type 18-8 steels cannot be considered as completely stable. With cooling below 0°C polymorphous transformation takes place with a formation of an oversaturated α -phase along the ***** mechanism α -hard solution (of martensite). Cold deformation contributes most strongly to martensitic transformation of chrome-nickel austenite of steel 18-8. Under the influence of stresses from cold hardening the transformation proceeds within the usual temperature range (150-250°C). The combined influence of cold hardening and deep cooling may cause a transition of the whole chrome-nickel austenite into martensite. In consequence of such treatment the hardness and toughness of the steel increases considerably at room temperature, and heat

endurance increases at temperatures of up to 450°C (fig. 58). At higher temperatures heat-endurance drops in connection with the annealing of martensite and partial re-crystallization.

Lately, in connection with the development of a number of special machine-building branches, the nomenclature of cast parts made of modified type 18-8 steel has considerably increased. Table 28 gives the composition of some brands of this type of steel. It also gives data on heat resistance at 650°C.

Table 28. Chemical composition and tensile strength of cast chrome-nickel austenitic steels of some brands

1) Brand of steel: 2) Chemical composition of investigated smelting batches, in %: 3) Limit of tensile strength in kg/mm² at 650°C during hours: 4) Relative elongation in % at the limit of tensile strength at 650°C for hours:

As it was already mentioned, one of the means of increasing heat-endurance of austenitic steels is increasing the content of the basic elements - chrome and nickel, while keeping to the general tendency of complex alloying.

Chrome-nickel steels of types 20-25, 25-20, 17-37 and 11-36. (The first figure is the content of chrome, the second - of nickel.) The characteristics of the resistance of these steels to creep are given in fig. 89; the tensile strength of steel 23-13 - in fig. 90. However, steels with a high content of nickel and especially of chrome are inclined toward embrittlement in consequence of prolonged heatings at high temperatures and the action of stresses. Evidently, the main cause of brittleness in chrome-nickel steels with high chromium content is the formation of σ -phase, which has the property to dissolve Mo, W, Al, Ni and others within a rather wide range.

In the production of cast type 20-25 steel additions of rare and rare-earth elements (Ce, Zr, Nd and others) are utilized. This increases plasticity and tensility, improves flowability and heightens resistance to scaling (up to 1050°C). At temperatures above 1100°C additions of rare-earth elements, on the contrary, lower scaling resistance (22).

The addition to type 20-25 steel of around 2% of silicon (Kh18N25S2)

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The addition to type 20-25 steel of around 2% of silicon (Eh18N25S2)

increases heat-endurance up to 1000-1100°C. However heat-endurance of the steel is comparatively low (fig. 91).

Fig. 88. Limits of tensile strength (1) and of creep (2) in steel of type 18-8 at 430°C. Preliminary treatment of samples: cold hardening by rolling with a compression extent of 40% at 75°C. Upper curve cross-cut samples; lower curve - longitudinal samples.

Ordinate: limit of strength, in kg/mm²

Abscissa (on top): Rate of creep, % per hour

(at bottom): hours

Fig. 89. Creep limit of chrome-nickel austenitic steels of type 20-25 at 10^{-5}/h (1), of type 25-20 (2), of 17-37 (3), and of 11-36 (4).

Ordinate: limit of creep, in kg/mm²

Abscissa: °C

Fig. 90. Tensile strength of steel Kh23N13: 1) at 550°C; 2) at 600°C; 3) at 650°C; 4) at 700°C

Ordinate: limit of strength Abscissa: hours

Fig. 91. Limits of creep for different summary (or total) deformation of steel Kh18N25S2 (Ye3S).

a) at 600°C; b) 650°C; c) at 700°C

Ordinates: limit of creep, in kg/mm^2

Abscissa: hours

Legends: destruction

Steel 4Kh14N14V2M (EI69) contains: 0.4-0.5% C, 0.3-0.8% Si, not over 0.7% Mn, not over 0.03% S, not over 0.03% P, 13-15% Cr, 13-15% Ni, 0.25-0.4% Mo, 2.0-2.75% W. The properties at room temperature are:

a) after heating to 820-850°C during 2 hours and cooling in air:

$\sigma_5 \geq 72$ kg/mm^2, $\sigma_T \geq 40$ kg/mm^2 $\delta_5 \geq 15\%$, $\psi \geq 35\%$: $\alpha_n \leq 4$ km/cm^2.

Fig. 92. Changes in strength of steel 4Kh14N14V2M after tempering for large and small grains, according to results of short-time tests for extension. 1 - tempering temperature 1180°C, large grain; 2 - tempering temperature 1100°C, small grain.

Ordinate: limit of ,
in kg/mm^2

Abscissa: °C

Fig. 93. Changes in plastic characteristics in large and small-grained steel of type 14-14-2 (4Kh14N14V2M) during short-time tests for extension.
1 - Tempering temperature 1100°C, small grain; 2 - tempering temperature 1180°C, large grain.

b) After tempering at from 1170–1200°C cooling in water: $\sigma_b \geq 70$ kg/mm^2, $\delta_5 \geq 35\%$, $\alpha_n \geq 10$ kg/cm^2. Sometimes tempering is followed by aging at 750°C during 5 hours.

Changes in toughness, according to results of hot short-time tests for extension after tempering for both large and small grains, are shown in fig. 92. Changes in properties of plasticity are shown in fig. 93.

Combined data concerning yield point and tensile strength of steel 4Kh14N14V2M at different test temperatures are given in fig. 94 and 95.

Fig. 94. Rate of creep in steel 4Kh14N14V2M at 600–700°C

Ordinate: limit of creep, in kg/mm^2

Abscissa: hours

Because of comparatively high carbon content, steel of type 4Kh14N14V2M has significant tendency toward aging, in which the formation of carbidic phases during heating proceeds for a long time. Simultaneous influence of high stresses and temperatures during work service leads to great structural

instability, connected with a drop of heat-resistant properties. Therefore in cases when steel of type 4Kh14N14V2M is intended for making parts which are to work at high temperatures under conditions requiring very long life, the composition of the steel is modified in such a way as to increase structural stability and to decrease the tendency for aging.

A definite, long-lasting effect was achieved by the introduction into the steel of 0.8-1.0% Nb (A. M. Borzdyka) and of titanium (steel EI123) which jointly form carbides soluble with difficulty in austenite at usual tempering temperatures. Therefore the quantity of carbon, which can form carbides during work, is decreased. An improvement of stability in steel 4Kh14N14V2M can be attained by decreasing carbon content. This was done in steel 1Kh14N14B2M (EI257), the carbon content of which does not exceed 0.15%.

Steel EI257 has found widespread use for making important parts of boilers and turbines of high parameters.

The mechanical properties of steel 1Kh14N14V2M at high temperatures are shown in fig. 96 and 97.

Fig. 95. Tensile strength of steel 4Kh14N14V2M (EI69) at 600-700°C
Ordinate: limit of strength, in kg/mm^2 Abscissa: hours

Fig. 96. Limits of tensile strength of steel 1Khl4Nl4V2M (EI257) at 550-700°C

Ordinate: Limit of strength, in kg/mm^2 Abscissa: hours

For a still greater improvement of structural stability in steel 14-14 a simultaneous decrease of carbon content and an addition of a strong carbide-forming element is sometimes carried out. Thus, steel 1Khl4Nl4V2MT was created. (Its composition: $\leq$ 0.15% C, $\leq$ 0.8% Si, $\leq$ 0.7% Mn, 13-15% Cr, 13-15% Ni, 2-2.75% W, 0.45-0.6% Mo, ~0.5% Ti.)

Fig. 97. Resistance to creep of steel 1Khl4Nl4V2M (EI257) at 550-650°C

Ordinate: Limit of creep, in kg/mm^2

Abscissa: Speed of creep, %/hour

Fig. 98. Resistance to creep of steel 1Khl4Nl4V2MT (EI257 with titanium) at 600-650°C

Ordinate: limit of creep, in kg/mm^2

Abscissa: speed of creep, %/hour

This steel is subjected to normalizing from 1100°C and aging at 850°C during 10 hours. Heat-resistant properties of steel EI257 with titanium are given in fig. 98 and 99.

Our industrial works produce still another variant of steel 14-14-2 called brand Kh14N14VS (EI240) containing: 0.4-0.5% C, 2.7-3.3% Si, ≤ 0.7% Mn (illeg.) -15% Cr, 13-14% Ni, ~ 0.5% Mo, 2.0-2.8% W.

Fig. 99. Tensile strength of steel 1Kh14N14V2MT (EI257 with titanium) at 600-650°C

Ordinate: limit of strength, in kg/mm²

Abscissa: hours

After therm. treatment consisting of heating to 820-850°C (during (illeg) .5 to 2 hours depending on cross-section) and cooling in air, the steel has satisfactory tensile strength at temperatures ~ 650°C (table 29) and good resistance to corrosion up to 1000°C.

Table 29. Limits of tensile strength of steel of type Kh14N14VS

1) Test temperature in °C; 2) Constant stress in kg/mm which causes destruction after the following time in hours

<u>Chrome-nickel-molybdenum steel of type 16-25-6</u> (corresponding to brand EI395 according to MPTU 2352-49). It contains: ≤ 0.12% C, 1.0-2.0% Mn, 0.5-1.0% Si, up to 0.02% S, up to 0.03% P, 15.0-17.5% Cr, 24.0-27.0% Ni, 5.5-7.0% Mo, 0.1-0.2% N_2.

The rational alloying of the steel determines its high heat-resistance together with great structural stability, which makes it possible to recommend steel 16-25-6 (EI395) for conditions of very long service (23). The stability of structure is enhanced also by the complex composition of the strengthening phase in the steel, which, according to our investigations, is only slightly inclined toward coagulation and has carbo-nitridic character. The formula of the strengthening phase of steel EI395 is: $(Fe, Ni)_2$, $(Mo, Cr)_4$, (CN). The greatest influence upon hardness increase in the steel after aging is exerted by carbon and molybdenum.

The mechanical properties of steel EI395 after various treatments are given in fig. 100 - 104.

The development of the tendency to increase the nickel content in steel together with a simultaneous addition of carbide-forming elements has led to the creation of a number of brands of heat resistant steels with a high nickel content. Among them the following have found use in our home industry.

Steel EI424: 0.1-0.16% C, 0.4-0.9% Si, 0.4-0.9% Mn, 14-16% Cr, 28-32% Ni, 1.5-2.0% Ti. The thermal treatment includes tempering at from 1200°C with cooling in water and aging at 700°C during 48 hours. The steel has a satisfactory heat-resistance at temperatures of 700-750°C (fig. 105 and 106).

Fig. 100. Results of tests for tensile strength of type 16-25-6 steel tempered at from 1200°C. Test temperatures: 1 - 650°C; 2 - 700°C; 3 - 750°C; 4 - 800°C.

Ordinate: limit of strength
Abscissa: hours

Fig. 101. Results of test for tensile strength of steel 16-25-6
1 - tempering at from 1200°C, cold hardening to 20% and aging at 700°C, test temperature 700°C; 2 - tempering at from 1200°C and aging at 700°C, test temperature 700°C; 3 - tempering at from 1200°C, cold hardening to 20% and aging at 800°C, test temperature 800°C;

Fig. 101 (continued). 4 - tempering at from 1200°C and aging at 800°C.

Ordinate: limit of strength, in kg/mm^2 Abscissa: hours.

Fig. 102. Limit of fatigue at room and high temperatures of type 16-25-6 steel after tempering at from 1200°C, cold hardening to 20% and aging at 800°C during 15 hours. a) test temperature 800°C, (illeg) equal 18.0 kg/mm^2; b) test temperature 700°C, $\sigma_{fat.}$ = 23.5 kg/mm^2; c) test temperature 650°C, $\sigma_{fat.}$ = 28.5 kg/mm^2; d) test temperature 20 C, $\sigma_{fat.}$ = 32 kg/mm^2.

Ordinate: limit of fat. $_{-1}$, kg/mm^2

Abscissa: number of cycles, millions.

Fig. 103. Limit of fatigue at room temperature and at high temperatures of type 16-25-6 steel after tempering at from 1200°C, cold hardening to 20% and aging at 700°C during 50 hours. a) test temperature 700°C, σ_{-1} = 27.0 kg/mm^2; b) test temperature 650°C, σ_{-1} = 28.5 kg/mm^2; c) test temperature 20°C, σ_{-1} = 35 kg/mm^2.

Ordinate: fatigue limit $_{-1}$, in kg/mm^2

Abscissa: number of cycles, millions.

Fig. 104. Characteristics of creep in steel 16-25-6 at 650-820°C

Ordinate: limit of fatigue, kg/mm²
Abscissa: Rate of creep, % per hour.

Fig. 105. Resistance to creep of steel EI424 at 650-700°C

Ordinate: limit of creep, kg/mm²
Abscissa: Speed of creep, % per hour.

Fig. 106. Tensile strength of steel EI424 at 600°C (temperating at 1200°C, cooling in water), and at 700°C (tempering and aging)

Ordinate: limit of strength, kg/mm²   Abscissa: hours.

However, because of a great capacity for aging the steel is not usable under conditions of long-life service (as it has a low plasticity after prolonged heatings at 650-700°C).

Fig. 107. Tensile strength of steel EI612 at 570-650°C

1 - smooth samples; 2 - samples with a corner notch.

Ordinate: limit of strength, kg/mm^2 Abscissa: hours.

Fig. 108. Resistance to creep of steel EI612

Ordinate: limit of creep, kg/mm^2 Abscissa: % per hour.

Fig. 109. Tensile strength of alloy EI692 at 650°C

Ordinate: limit of strength, kg/mm^2 Abscissa: hours

Steel EI612: $\leq$ 0.12% C, 0.25-0.5% Si, 1-2% Mn, 2.8-3.2% W, 14-16% Cr, 34-38% Ni, 1.1-1.4% Ti. After tempering at from 1150°C with cooling in water, the steel is subjected to double aging:

a) at 740-760°C during 10 hours,

b) at 700-710°C during 25-50 hours.

The limits of tensile strength and creep of steel EI612 are given in fig. 107 and 108. The steel is used for making turbine vanes working at temperatures of 650-680°C.

Steel EI692: $\leq$ 0.08% C, up to 1.0% Mn, up to 0.5% Si, 14.5-16% Cr, 36-38% Ni, 2.3-3.0% W, 2.3-3.0% Mo, 1.2-1.4% Ti. The properties of the alloy, according to data of A. M. Borzdyk, are given in table 30 and in fig. 109 and 110.

High heat-resistant properties are possessed by chrome-nickel-manganese steels additionally alloyed with vanadium, molybdenum, tungsten and other elements. In our country steels of this type are successfully developed by F. F. Khimushkin with his collaborators.

It is rational to carry out the alloying of chrome-manganese austenitic steels with elements with elements that would counteract the impairing influence of manganese upon some technological properties and also upon the formation of σ-phase, and would, at the same time, secure an increase of heat-resistance through joint alloying.

Fig. 110. Resistance to creep of alloy EI692 at 650°C

Ordinate: limit of creep, kg/mm^2 Abscissa: rate of creep, % per hour

As many investigations have shown, a partial replacement of manganese with nickel (5-8%) is very effective.

The addition of nickel promotes the obtaining of stable austenite, decreases the tendency of the steel to lose some of its static and dynamic tensility in consequence of repeated heatings, and increases resistance to corrosion by gases.

Below are given characteristics of the properties of some austenitic chrome-nickel-manganese steels used in our home industries that have been additionally alloyed, in a number of cases, with tungsten, molybdenum, vanadium or silicon.

Steel of type 2Kh13N4G9. According to data by Zuyev, and others, the steel has the following mechanical properties after annealing at 850-900°C:

Test temperature °C   700   800   900

Mechanical properties:

Tensile strength σ_6, in kg/mm^2	22.5	14.6	7.1
Elongation δ_5, in %	34.3	34.6	35.7
Narrowing of cross-section ψ, in %	71.9	76.1	78.9
Resilience a_η, in kg/cm^2	13.5	15.[illegible]	21.1
Hardness H_b	122	88	71

Table 30. Mechanical properties of steel EI692 at room and heightened temperatures

1) Properties:

Limit of strength, in kg/mm^2

Limit of creep, in kg/mm^2

Elongation, in %

Narrowing of cross-section, in %

Resilience, in kg/cm^2 after 2500 hours of heating at 700°C

Tensile strength in kg/mm^2 for a time duration of hours: 1000, 10,000, 1,000,000

Limit of creep (yield point) in kg/mm for a creep rate of 10^{-4}%/hour

10^{-5}%/hour

2) Test temperature in °C.

Steel of type 4Khl8N6G5 (This steel was used, in its time, as a substitute for the more expensive highly nickelic steel of type 4Khl4N14V2M for making valves of powerful engines.) It contains: 0.2-0.4% Mo and 0.8-1.3% W (EI310). It is usually subjected to annealing at 850°C during 2 hours. After this it has the following mechanical properties:

Test temperature, °C	700	800	900
Mechanical properties:			
Tensile strength σ_t, in kg/mm^2	28	18	8
Elongation δ_5, in %	40	45	66
Narrowing of cross-section ψ, in %	60	65	80
Resilience α_η, kg/cm^2	7	8	16

Steel of type 4Khl4N3G8, containing 0.4-0.8% Mo and 1.4-1.8% V (EI310), us subjected to treatment for dispersion hardening: Tempering at from 1160-1200°C with cooling in water or in air, and aging at 800°C. After this treatment the steel has a high yield point. With a deformation speed of 0.2% for 100 hours it is: at 500°C 24.5 kg/mm , at 600°C 20.0, at 700°C 12.5, at 800°C 7.8 kg/mm^2. Data concerning tensile strength are given in table 31.

F. F. Khimushkin points out, that the heat-resistance of steel EI388 (as also of many other alloys based on iron and nickel) drops sharply when the structure contains great disparity in grain sizes. This usually occurs when

Table 39. Limits of tensile strength in steel 4Kh14N3S3

1) Treatment:

   Tempering at from 1190°C

   Same

   Tempering at from 1190°C plus aging at 700°C

   Tempering at from 1190°C plus aging at 800°C

2) Test temperature in °C

3) Limits of tensile strength in kg/mm² for a time in hours

in a piece of work (or in an item being made) some volumes are deformed to the critical degree during forging or stamping. Then, during a subsequent heating to a high temperature for tempering, these volumes get a large-grained structure.

When items being made, or samples with variously-sized grains in the structure, are subjected to stresses at high temperatures, the volumes of small-grained structure, which have lesser heat resistance and greater plasticity, deform easily. Therefore the volumes of large-grained structure and slight plasticity (that do not deform as much) must bear a large load. This caused premature cracking along grain limits.

It was established, that cracks appear during work first of all on the junctions of larger and smaller grains, and that a working part has a life length in proportion to the uniformity or disparity of grainsizes.

SOME DOMESTIC HIGHLY HEAT-RESISTANT AUSTENITIC STEELS USED IN MOTOR BUILDING

Chrome-manganese-nickel steel of brand EI481. (Average content: 0.38% C, 13% Cr, 8% Ni, 8% Mn, 1.3% V, 1.1% Mo, 0.3% Nb.) This steel has found use in making turbine disks of the most varied dimensions weighing from 50 to 500 kg and with diameters of up to one meter. It is also used for band rings (joining the disks), deflector shields, labyrinth packings, and re-enforcing details.

Fig. 111-113 show changes in mechanical properties of steel EI481 in dependence upon test temperatures. The data given are for samples with a hardness (along the diameter of the impression) of 3.3 and 3.55 mm. A harder steel, that results from aging at 650-700°C, has great toughness but a lowered and unstable heat resistance because of a sensitiveness of the steel to notching at working temperatures (650°C). This is corroborated by tests of smooth and notched samples and tests of disks on power-producing machines.

In order to decrease the sensitiveness to notching a double aging was proposed (first aging at 690°C during 15 hours and a second aging at 780-800°C

during 10-15 hours). Such treatment secured a good heat-resistance and durability of the disks at work, especially along the rim.

In order to raise the limit of strength and the yield point of the material at the hub of the disk, it is recommended that the whole disk be subjected to the first aging and then to do the second aging at 800°C only along the rim of the disk in order to soften it.

There are further possibilities of economizing on nickel in steel EI481 by reducing its content to 5%, and also by excluding niobium from the composition of the steel through the use of purer iron in smelting. Brand EI734 steel has practically the same properties (fig. 114) as brand EI481 steel, and it is recommended for a number of parts working at high temperatures (bands, bolts, cotter pins and disks).

<u>Chrome-nickel-titanium steel of brand EI696</u> is used for making turbine disks, powered (or stressed) parts of turbine vanes, coupling rings, shafts, parts of bell mouths. Chambers of final combustion made of steel EI696 worked fully satisfactorily at working temperatures up to 800°C. The raising of working temperatures in the compressor brought forth the use of this steel for vanes and disks of shaft compressors in gas turbine installations.

Fig. 111. The dependence of the mechanical properties of steel EI481 upon temperature. Short-time tests for tensile strength. The steel is processed for a hardness d_{omm} = 3.3 mm. (The steel is susceptible to notching.)

Left ordinate: , in kg to mm^2

Right ordinate: "E", in kg to mm^2

Abscissa: Temperature in degrees C.

At curves from top to bottom.

Fig. 112. The dependence of the mechanical properties of steel EI481 upon temperature. Short-time tests for tensile strength. The steel is processed for a hardness d_{omm} = 3.55 mm. (The steel is not susceptible to notching.)

Left ordinate: , in kg to mm^2

Right ordinate: E, in kg to mm^2

Abscissa: Temperature, in degrees C.

In its heat-enduring properties, steel of brand EI696 is very close to the nickel alloy of brand EI437B, equivalent to alloy EI437A (see page 745) and is one of the most heat-enduring steels among iron-based alloys.

The fluctuation of heat-endurance properties of brand EI696 steel is shown with test temperatures in fig. 115. At 500 to 650°C this steel is somewhat

Fig. 113. Limits of stress rupture strength of steel EI481 (processed for a hardness of $d_{omm} = 3.55$) at 600 to 750°C

Left ordinate: Limit of tensile strength, in kg to mm^2

Abscissa: hours

inferior to alloy EI437B, while at 700 to 750°C it is very close to the latter.

In comparison with steel EI481, steel of brand EI696 has greater heat-endurance and is, therefore, recommended for making most stressed turbine disks.

Fig. 114. The dependence of the mechanical properties of steel EI734 upon temperature. Short-time tests for tensile strength.

Fig. 115. The results of tests of steel EI696 samples at high temperatures. Thermal treatment: tempering at from 1150°C (cooling in air and aging at 700 to 750°C during 16 hours).

Fig. 114. (continued)

Left ordinate: kg to mm^2

Right ordinate: E, in kg to mm^2

Fig. 115. (continued)

Left ordinate: Limits, in kg to mm^2, of

δ, ψ in %

Right ordinate: E, in kg to mm^2

Abscissa: Temperature, degrees C.

In producing steel EI696 special attention is given to the presence in the ingredients of material batches, especially rion, of injurious admixtures - lead, tin, antimony, bismuth and others, the content of which must be minimal. Boron has a very great influence upon heat-endurance properties, as may be seen from the comparison of data given in table 32.

The part played by aluminum is not yet definitively ascertained, but it is established, that in objects of small cross-sections high heat-enduring properties are obtained both when using steel with small aluminum content (0.10%) and when using steel with a heightened aluminum content (0.80%).

High heat-endurance properties of steel EI696 are obtained after corresponding thermal processing, consisting of tempering at temperatures of from 1100-1200°C and subsequent aging at 700-800°C. The thicker the cross-section of the object, the higher the temperature of tempering and aging must be. For small cross-sections (with diameters of not over 80 mm) good results are obtained after tem-

Table 32. Influence of Boron on tensile strength of steel EI696 (Heat treatment: tempering at 1100°C, cooling in air, aging at 700°C, in crucible 16 hrs, cooling in air

1) No. of melt
2) Testing temperature in °C
3) σ in kg/mm^2
4) Time to destruction (in hours)
5) δ in %
6) ψ in %
7) 894-1 (without B)
8) Calculated content
9) not destroyed

pering in open air at 1100 to 1150°C, and for larger cross-sections, after tempering in air at 1150 to 1180°C. In the first case aging during 16 hours at 700°C is sufficient, while in the second case it is necessary to raise the temperature of aging up to 750-800°C. The higher the content of titanium and aluminum in the steel, the higher its capacity for hardening during aging within the range of moderate temperatures, and the lower the plasticity of the steel after aging. The steel has minimum toughness and hardness in the tempered state beginning at temperatures of 1100 to 1200°C. During the process of heating tempered steel within a temperature range from 450 to 800°C a variation of hardness is observed (fig. 116).

Fig. 116. Changes in hardness of steel EI696 in dependence upon temperature and the duration of aging

Right ordinate: Hardness Abscissa: hours

The properties of steel EI696 at 20°C are given in table 33.

Steel EI696 welds completely satisfactorily, but requires the observance of special welding conditions. Best of all it is forged and welded in a state of having been tempered for austeniticity (tempering in air at from 1100°C). Subsequently the parts for welding are subjected to aging at 700 to 750°C during 5 to 16 hours in order to heighten their heat-endurance and toughness. During spot and roller welding a higher pressure of electrodes is necessary, while during argon-arc welding a steadiness of welding condition is indispensible to avoid the appearance of defects (cracks), as it is hard to weld them over. Steel EI696A, containing 2.4 to 2.7% Si and 0.003% B and with lowered aluminum content, welds better. By manual welding the steel welds well.

Basic highly durable austenitic steels used abroad.

Steel Rex 78: $\leq$ 0.12% C, $\leq$ 1.0% Mn, $\leq$ 1.0% Si, 17 to 18.5% Ni, 13 to 14.5% Cr, 3.5 to 4.5% Cu, 3.5 to 4.5% Mo, 0.5 to 1.0% Ti, ~ 0.25% V, is used for disks and vanes of gas turbines. The steel is tempered at from 1050°C (with air cooling) and subjected to double aging:

a) at 800°C during 3 hours, cooling in air;

b) at 600°C during 48 hours, cooling in air.

Table 33. Mechanical properties of steel EI696 at room temperature.

1) Smeltings: a) smelted in an induction furnace (6 smeltings),
b) smelted in arc furnace (7 smeltings),
c) smelted in arc furnace (15 smeltings),
d) arc furnace (3 smeltings).

2) Kind of semi-finished product: a) rod, 32 mm in diameter, rod 26 mm in diameter,
b) forgings, 90 mm in diameter,
c) forgings, 90 mm in diam.,
d) forgings, 90 mm in diam,
e) forging

3) Conditions of thermal treatment: a) Tempering at from 1100°C (during 2 hours), cooling in air, aging during 16 hours in air,
b) Tempering at from 1100°C (during 2 hours), cooling in air, aging at 700°C during 16 hours, cooling in air. Tempering at from 1100°C (during 2 hours), cooling in air, aging at 750°C during 16 hours, cooling in air,

Table 33. (Continued). (3)

c) Tempering at from 1150-1200°C (during 2 Hours), cooling in air, aging at 700°C during 16 hours, cooling in air. Tempering at from 1180-1200°C (during 2 hours), cooling in air, aging at 750°C during 16 hours, cooling in air.

d) Tempering at from 1130°C (during 3-5 hours), cooling in air, aging at 700°C during 16 hours, cooling in air. Tempering at from 1130°C (during 5 hours), cooling in water, aging at 700°C during 16 hours, cooling in air,

e) Tempering at from 1160°C (during 2-3 hours), cooling in water, aging at 750°C during 10-16 hours, cooling in air.

4) Accorind to data of Electrosteel and VIAM

The heat-endurance properties are illustrated by graphs in fig. 117.

Steel 19-9 W, Mo: 0.08% C, 8 to 10% Ni, 18 to 22% Cr, 0.2 to 0.5% Mo, (illeg) -1.5% W, 0.2 to 0.6% Nb, 0.2 to 0.6% Ti, is used in gas turbine construction. The steel is subjected to tempering in water at from 1100°C and to aging at 650°C during 4 hours, or to hot hammer hardening with subsequent aging at 650°C during 4 hours. The latter treatment is used more often. The heat-endurance properties after this treatment are shown in fig. 118.

Steel 19-9 DL: 0.25 to 0.35% C, 8 to 10% Ni, 18 to 22% Cr, 1.0 to 1.5% W, (illegible) 0.6% Nb, 0.2 to 0.6% Ti. The calculated curves for a temperature of 730 C after two variants of thermal treatment (a - semi-hot hammer hardening and aging at 730°C and b - tempering at from 1200°C and aging at 730°C) are presented in fig. 119.

Steel G-18-B (in composition it is close to steel EI434): 0.4% C, 1[illegible] Ni, 13% Cr, 10% Co, (illegible) .5% Mo, 3% W, 3% Nb. Data concerning the resistance to creep within the limits of tensile strength of the steel at temperatures of 600 to 900°C are presented in fig. 120. The fatigue limit of the steel is shown in fig. 121.

Steel Multimet N-155: 0.08 to 0.16% C, 19 to 21% Ni, 21 to 22% Cr, 18.5 to 21.0% Co, (Illegible) .5 to 3.5% Mo, 2 to 3% W, 0.75 to 1.75% Nb, 0.1 to 0.2% N_2. The characteristics to tensile strength and of resistance to creep are presented in fig. 122.

Fig. 117. The limits of creep and of tensile strength of steel Enx-78.

1 - rate of creep 0.2% for 300 hours;

2 - rate of creep 0.2% for 1000 hours;

3 - tensile strength for 1000 hours.

Left ordinate: limit of creep, of tensile strength, in kg to mm^2.

Abscissa: Temperature, °C

Fig. 118. Limits of creep and of tensile strength of steel 19-9E Mo.

1 - rate of creep 10^{-6}%/hour;

2 - rate of creep 10^{-7}%/hour;

3 - tensile strength for 1000 hours;

4 - tensile strength for 10,000 hours.

Ordinate: Limits of creep, strength, in kg to mm^2

Abscissa: Temperature, °C

Steel Discalloy: 0.05% C, 25% Ni, 13% Cr, 3% Mo, 0.5% Ti, 0.2% Al.

Thermal treatment: heating to 1065°C, cooling with the furnace or in oil, aging at 730°C during 20 hours. Calculated curves for 650°C are shown in fig. 123. The values of durable strength and resistance to creep are given in fig. 124.

Fig. 119. Calculated curves of alloy 19-9 DL for a temperature of 730°C

a) After semi-hot hammer hardening and aging at 730°C

b) After tempering at from 1200°C and aging at 730°C

Figures at the curves signify total stretch (or summary elongation)

Above vertical column of figures: limit in kg to mm².

Figures at bottom: hours

Legends, from top to bottom:

Destruction; 3rd stage of creep;

3rd stage of creep; Destruction.

Fig. 120. The limits of creep and durable strength for steel G-18-B

Speed of creep: 1) 0.1% after 300 hours;

2) 0.1% after 1000 hours;

3) 0.1% after 3000 hours

Durable strength: 4) after 300 hours;

5) after 1000 hours;

6) after 10,000 hours

Above vertical column of figures: kg to mm²

Figures at bottom: Temperature, in °C

Fig. 121. Limits of fatigue for steel G-18-B

Above vertical column of figures: kg/mm^2

Figures below: Number of cycles.

Fig. 122. Limits of durable strength (a) and of creep (b) for steel E-155

Above vert. col.: kg/mm^2 Figures at bottom: hours

Legend: Speed of creep, %/hour

Fig. 123. Calculated curves of steel Discalloy for 650°C. Figures at curves denote elongation

Ordinate: Limit, in kg to mm^2 Abscissa: hours

Legends from top: 1) 3rd stage of creep; 2) destruction

Fig. 124. Limits of creep and durable strength for Discalloy steel

a) durable strength: b) Creep limit

Above vert. col.: kg/mm^2 Figures at bottom: hours

Legend: Rate of creep

Steel A-286: up to 0.08% C, 24 to 28% Ni, 13.5 to 16% Cr, 1.0 to 1.5% Mo, (illegible) .5 to 2.25% Ti, 2% Al, 0.3% V. Thermal treatment: tempering at from 1000°C, cooling in water, aging at 720°C during 16 hours. Characteristics of resistance to creep and of tensile strength are given in fig. 125.

Steel S-590: 0.5% C, 20% Ni, 20% Cr, 20% Co, 4% Mo, 4% W, 4% Nb. Thermal treatment: tempering at from 1200°C in oil or in air, aging at 760°C during 16 hours.

The results of testing this steel for tensile strength and creep are given in fig. 126.

Attempts were made to improve the properties of the steel by addition to it vanadium and nitrogen. However, these elements impaired heat-endurance. The

Fig. 125. Limits of creep and of durable strength for steel A-286

a - durable strength; b - creep limit.

Above vert. col.: kg/mm^2 Figures at bottom: hours

Legend: Rate of creep

Fig. 126. Limits of creep and of durable strength of steel S-590

a - durable strength; b - creep limit.

Above vert. col.: kg/mm^2 Figures at bottom: hours

Legend: Rate of creep

Introduction of titanium into chrome-nickel-cobalt-tungsten steel of type S-590 proved to be very effective. The data obtained after tempering at from 1100°C and aging at 700°C during 24 hours are shown in table 34.

Table 34. Mechanical properties of steel S-590

1) Content of Ti, in %   2) Limit of resilience, in kg/mm^2

3) Time until destruction under   = 26 kg/mm^2 at 700°C

<u>Steel HNM</u>: 0.31% C, 3.43% Mn, 0.50% Si, 9.5% Ni, 19% Cr, 3% P. The optimum (or best) conditions of the steel's thermal treatment: tempering in oil at from 1095°C and aging at 760°C during 16 hours. An increase of tempering temperature was followed by an increase of durability and a decrease of plasticity. The hardness of steel HNM after tempering in oil is H_{R_C} = 33. The mechanical properties of the steel are presented in table 35.

A comparison of tensile strengths for 100 and 1000 hours as well as of the yield points, which causes an elongation of 1% during 10,000 hours, for some of the above-mentioned highly alloyed austenitic steels is given in fig. 127 to 129.

Fig. 127. Comparison of values of tensile strength for 100 hours of a number of highly alloyed austenitic steels

1 - S -816; 2 - A-286; 3 - Discalloy; 4 - S590; 5 - N-155; 6 - 16-25-6; 7 - 19-9 DL.

Ordinate: Limit of strength, in kg to mm^2

Abscissa: Temperature, ^oC

Fig. 128. Comparison of the values of tensile strength for 1000 hours of a number of brands if highly alloyed austenitic steels

1 - S-816; 2 - A-286; 3 - Discalloy; 4 - S-590; 5 - N-155; 6 - 16-25-6; 7 - 19-9 DL

Ordinate: Limit of strength, in kg to mm^2

Abscissa: Temperature, ^oC

Fig. 129. Comparison of the values of creep limit which causes an elongation of 1% for 10.000 hours (0.0001% per hour) for a number of brands of highly alloyed austenitic steels

1 - A-296; 2 - Discalloy; 3 - S590; 4 - S816; 5 - N-155; 6 - 15-25-6; 7 - 19-9 DL

Ordinate: Limit of creep, in kg to mm2

Abscissa; Temperature, oC

Table 35. Mechanical properties of steel HEM at high temperatures. (Thermal treatment: temperating at from 1093°C during 0.5 hours, cooling in oil, aging at 760°C during 16 hours, cooling in air. Hardness at 20°C H_{R_C} = 33.

1) Temperature in $^\circ C$ 2) Limit of strength, in kg/mm^2

3) Limit of creep in kg/mm^2 4) Relative elongation (or stretching), in %

5) Relative narrowing (or contraction) of cross-section, in %,

6) Limit of tensile strength, for 100 hours, for 1000 hours.

HEAT-RESISTING ALLOYS ON NON-FERROUS BASES

Alloys on the basis of nickel. Alloys of type Hastalloy are used in three variants:

a) Hastalloy A: 0.04 to 0.15% C, 18 to 22% Fe, 18 to 22% Mo, 0.8% Si, the remainder being nickel;

b) Hastalloy B: up to 0.12% C, 4 to 7% Fe, 26 to 30% Mo, 0.6% Mn, 0.2% Si, 0.3% V, the remainder being nickel;

c) Hastalloy C: up to 0.15% C, 1.5 to 17.5% Cr, 4.5 to 7% Fe, 16 to 18% Mo, 3.75 to 5.25% W, the remainder being nickel.

These alloys are used both in a cast and in a forged form. However, the cast form gives a higher level of heat-endurance properties. Forging is done within a temperature range of from 1230 to 1000°C. The alloys may be subjected to treatment for dispersional hardening; tempering beginning at temperatures of 1180-1220°C, cooling in water or in air and aging at 850°C during 16 hours. The results of short-time tests of forged samples of Hastalloys B and C at room and high temperatures are presented in table 36. The limits of tensile strength of forged alloy. Hastalloy B are given in table 37, while the combined results of

short-time tests for stretching, tensile strength and creep of cast alloys of Hastalloys A, B are shown in tables 38 and 39.

Table 36. Mechanical properties of alloys Hastalloy B and C
(tests for short-time stretching)

1) Hastalloy B: Test temperature in °C; Limit of strength, in kg/mm²

2) Hastalloy C: Test temperature, in °C; Limit of strength, in kg/mm²
Relative elongation, in %.

3) Note: Thermal treatment of Hastalloy B: annealing at 1180°C
of Hastalloy C: annealing at 1200°C

Table 37. Tensile strength of alloy Hastalloy B

1) Test temperature, in °C 2) Limits of tensile strength in kg/mm² with the following duration of test in hours 3) Note: Thermal treatment of samples: heating to 1170°C, cooling in air, aging at 925°C during 72 hours.

Table 38. Mechanical properties of cast alloys Hastelloy A, B and C

1) Alloy   2) Short-time tests for extension: (a) Test temperature, in °C

(b) Limit of strength, in kg/mm^2,

(c) Relative elongation (or stretch) in %

3) Test temperature, in °C

4) Limit of tensile strength, in kg/mm^2, with a test duration in hours

Table 39. Creep characteristics of cast alloy Hastalloy C in a test duration of 500 hours

1) Test temperature, in °C

2) Processing: (a) After casting, (b) Same, (c) After casting - aging at 870°C during 16 hours, (d) Same.

3) Magnitude of tension in kg/mm²

4) Initial deformation

5) Creep rate in % per 1000 hour

6) Total deformation in %

An alloy, Hastalloy X, which is a substitute for Hastalloys A, B, and C, was developed recently. The composition of Hastalloy X is: 0.15% C, 22% Cr, 9% Mo, 24% Fe, the remainder being nickel. The alloy contains a decreased quantity of difficulty obtainable alloying elements. However, notwithstanding this, it has sufficient heat endurance and high-temperature oxidation resistance, which makes it possible to use it for making parts of combustion chambers for reactive motors.

Alloy XA-22X, which contains 26 to 29% Cr, 4 to 6% W, 11 to 18% Fe, ~ 0.5% Mn, ~ 1.5% Si, the remainder being nickel, is also used in the USA as sheet material for combustion chambers. This alloy has good resistance to oxidation up to 1200°C and good heat-endurance also. The stress causing destruction of a sample after 100 hours at 985°C is equal to 3.64 kg to mm² and at 1200°C equal to 0.7 kg to mm². For 1000 hours at 985°C it is equal to 2.52 kg to mm², at 1200°C to 0.35 kg to mm².

Fig. 130. The results of high-temperature tests for fatigue and creep of alloy Inconel W

1 - the limit of fatigue for 10 (illeg) cycles at room temperature, fat. = 36.2 kg/mm^2; 2 - limit of stress with a creep rate of 1% for 10 hours

Ordinate: limit of creep, in kg/mm^2

Abscissa: Temperature, °C

Fig. 131. Limits of creep and of tensile strength of alloy Inconel X

1 - tensile strength for 100 hours; 2 - tensile strength for 1000 hours; 3 - speed of creep 10^{-6}%/hour; 4 - speed of creep 10^{-7}%/hour for 100 hours.

Alloy Inconel W; 0.05% C, 14% Cr, 6% Fe, 2.5% Ti, 0.6% Al, the remainder being nickel. This alloy, like all alloys based on nickel, must have a very low sulphur content (< 0.01%). Thermal treatment of the alloy:

tempering at from 1150°C (during 2 to 4 hours), cooling in water, aging at 850°C during 24 hours. Resistance to creep and to destruction through fatigue at high temperatures is shown in fig. 130. The limits of tensile strength are given in table 40.

<u>Alloy Inconel X</u> has approximately the following chemical composition: up to 0.08% C, 14 to 15% Cr, 5 to 9% Fe, 0.7 to 1.2% Nb, 2.25 to 2.75% Ti, 0.7% Mn, 0.4% Si, 0.7% Al. The following conditions of thermal treatment are recommended: tempering at from 1150°C during 2 to 4 hours, cooling in air; then the first aging at 850°C during 24 hours and a second aging at 700°C during 20 hours. The alloy has sufficiently high properties of durability when heated (fig. 131). The characteristics of the resistance of alloy Inconel X to destruction through fatigue at high temperatures are given in table 41.

Table 40. Limits of tensile strength of alloy Inconel W

1) Temperature, in °C 2) Limit of tensile strength in kg/mm² with a test duration in hours

Table 41. Fatigue limit of alloy Inconel X at heightened temperatures

1) Test temperature, in ^{o}C 2) Limit of fatigue in kg/mm^2 with the number of cycles

<u>Alloy Refractalloy 26</u> contains on the average: 0.03% C, 18% Cr, 20% Co, (illegible) % Ce, 3% Mo, 3% Ti, 0.8% Mn, 1.0% Si, 0.2% Al, the remainder being nickel. Thermal treatment consists of tempering at from 1150°C, cooling in water and in air, and aging at 730°C during 20 hours for hardness H_B = 250 ÷ 340. The results of tests for tensile strength and creep at temperatures of 650 to (illegible) °C are presented in figure 132.

<u>Alloy M-252</u>: 0.17% C, 19% Cr, 10% Co, 1 to 2% Fe, 11% Mo, 2.3% Ti, the remainder being nickel. Thermal treatment: tempering at from 1060 to 1070°C during 4 hours, slow cooling with the furnace to 540°C, then in air. Durable strength - see figure 133. Fatigue endurance in comparison with alloys Nimonic 80 and S-616 - see fig. 134.

Fig. 132. Limits: 1 - of creep (rate of creep 0.2% for 450 hours); 2 - of tensile strength for 100 hours for alloy Refrectalloy 26

Ordinate: limits of creep, of strength, in kg/mm^2

Abscissa: Temperature, °C

Fig. 133. Tensile strength of alloy M-252

Ordinate: limit of strength, in kg/mm^2

Abscissa: hours

Some of the best heat-enduring alloys on nickel bases are the alloys of type Nimonic, based on nickel and chrome, in the proportion of 80 to 20. A rational alloying of this composition with titanium and aluminum at the expense of nickel has resulted after appropriate thermal treatment in a sharp increase of heat-enduring properties.

The influence of titanium and aluminum upon heat-enduring properties of the nickel-chrome bases is well illustrated by the curves of fig. 135. Depending upon the degree of alloying with the former, as well as with other elements (cobalt, molybdenum, tungsten) heat-enduring properties change considerably, a fact which has given a basic reason for creating a series of alloys of type Nimonic.

Nimonic 75: 0.08% to 0.15% C, 18 to 21% Cr, up to 5% Fe, 0.2 to 0.6% Ti, 1.0% Mn, up to 1.0% Si, the remainder being nickel. Thermal treatment: tempering at from 1270°C cooling in water. In consequence of the tempering a practically uniform large-grained structure of the hard solution based on nickel is fixed. Due to the small titanium content the alloy Nimonic 75 has low tensile strength at high temperature (table 42). The alloy is easily deformed, welds well and has high resistance to oxidation. This determines its use as sheet material out of which parts of heating pipes and combustion chambers for reactive motors are made. In recent time a multilayer material is used (the English call it "sandwich material") which consists of a sheet of copper rolled between two sheets of alloy Nimonic 75. In these conditions heat conductivity is improved and the durability of parts is increased.

Nimonic 80: up to 0.06% C, 19 to 22% Cr, up to 1% Fe, 2.2 to 2.8% Ti, up to 0.35% Mn, up to 0.65% Si, 0.5 to 0.95% Al, the remainder being nickel. Thermal treatment: tempering at from 1080°C during 8 hours, cooling in water or in air, aging at 700°C during 16 hours.

Nimonic 80A has a composition almost analogous to that of Nimonic 80, but its content of aluminum and titanium corresponds to the upper limit

Fig. 134. Fatigue strength of alloy M-252 in comparison with alloys Nimonic 80 and S-816 at high temperatures; 1 - Nimonic 80; 2 - 816; 3 - M-252

Ordinate: Limit, in kg/mm^2 at 10^8 cycles

Abscissa: Temperature, $^{\circ}$C

Fig. 135. The results of tests for creep of alloys of type 80% Ni - 20% Cr, with different contents of titanium and aluminum. Magnitude of constant stress $\sigma = 37$ kg/mm^2; temperature 650°C

($\sim$2.8% Ti and up to 1.0% Al). The thermal treatment of alloy Nimonic 80A does not differ from the treatment of the preceding alloy. The results of tests of alloys Nimonic 80 and Nimonic 80A for creep and tensile strength are presented in figures 136 - 139.

Nimonic 90 contains up to 0.1% C, 18 to 21% Cr, 15 to 20% Co, less than 1.0% Fe, 2.0 to 2.8% Ti, 0.8 to 1.2% Al. The conditions of thermal treatment are the same as for alloy Nimonic 80. Data concerning tests for tensile strength and for creep and given in figures 140 and 141.

Table 42. Mechanical properties of alloy Nimonic 75 at heightened temperatures

1) Short-time extension. (a) Test temperature, in °C, (b) Limit of strength, in kg/mm², (c) nominal limit of creep, in kg/mm², (d) Elongation (or stretch) in %. 2) Creep limit in kg/mm² with an elongation of 0.1% for 300 hours at test temperatures in °C

The characteristics of the resistance to destruction through fatigue at room and heightened temperatures for alloys Nimonic 80, Nimonic 80A and Nimonic 90 are given in table 43. The comparatively high fatigue characteristics of alloy Nimonic 90 give a basis for making specialized machine building out of this alloy spiral springs which work successfully at high temperatures.

Nimonic 95 is similar to alloy Nimonic 90. However, it has higher heat-enduring properties in consequence of some increase of titanium and aluminum content (up to 3.0% Ti and 1.5% Al). The thermal treatment of alloy Nimonic 95 somewhat differs from the treatment of other alloys of the Nimonic type and provides for a double tempering:

Fig. 136. Creep characteristics of alloy Nimonic 80: 1 - Creep 0.2% for 100 hours; 2 - creep 0.2% for 1000 hours; 3 - creep 0.2% for 5000 hours; 4 - creep 0.2% for 10,000 hours.

Ordinate: limit of creep, in kg/mm^2

Abscissa: Temperature, $^{\circ}$C

Fig. 137. Tensile strength of alloy Nimonic 80.

Ordinate: limit of strength, in kg/mm^2

Abscissa: hours

At curves (from top to bottom): 300 hours, 1000 hours, 5000 hours, 10,000 hours.

Fig. 138. Creep characteristics of alloy Nimonic 80A: 1 - creep 0.2% for 300 hours; 2 - creep 0.2% for 1000 hours; 3 - creep 0.2% for 5000 hours; 4 - creep 0.2% for 10,000 hours.

Ordinate: creep limit, in kg/mm^2

Abscissa: Temperature, $^{\circ}$C

Fig. 139. Tensile strength of alloy Nimonic 80A: 1 - for 300 hours; 2 - for 1000 hours; 3 - for 5000 hours; 4 - for 10,000 hours.

Ordinate: limit of strength, in kg/mm^2

Abscissa: Temperature, $^{\circ}$C

Fig. 140. Creep characteristics of alloy Nimonic 90: 1 - creep 0.2% for 300 hours; 2 - creep 0.2% for 1000 hours; 3 - creep 0.2% for 5000 hours.

Ordinate: Creep limit, in kg/mm^2

Abscissa: Temperature, $^{\circ}$C

Fig. 141. Tensile strength of alloy Nimonic 90: 1 - for 300 hours; 2 - for 1000 hours; 3 - for 5000 hours

Ordinate: limit of strength, in kg/mm^2

Abscissa: Temperature, $^{\circ}$C

Table 43. Characteristics of fatigue strength of Nimonic type alloys at room and heightened temperatures

1) Alloy: Nimonic 80, 80A, 90
2) Limit of fatigue in kg/mm^2 for 40.10 (illegible) cycles at temperatures in $^{\circ}$C:

a) first tempering: temperature of 1200°C during 1 to 2 hours, cooling in air;

b) second tempering: from 1000°C during 6 to 8 hours, cooling in air.

The final operation is the usual aging at 700°C during 16 hours. The properties of alloy Nimonic 95 after thermal treatment are given in tables 44 and 45.

Table 44. Mechanical properties of alloy Nimonic 95 at high temperatures according to data of short-time tests for extension (or stretch) at high temperatures

1) Test temperature, in °C; 2) Limit of strength, in kg/mm^2; 3) Nominal limit of creep 0.1%, in kg/mm^2; 4) Relative elongation, in %; 5) relative narrowing of cross-section, in %; 6) Modulus of resilience $E.10^4$, in kg/mm^2

Nimonic 100 has the composition: ~0.3% C, 1 to 2% Ti, 10 to 12% Cr, 4 to 6% Al, 4.5 to 5.5% Mo, up to 0.5% Si, up to 2% Fe, 18 to 20% Co, the remainder being nickel. It has higher heat-enduring properties (table 46) than Nimonic 95, which makes it possible to use items made out of it at higher temperatures (higher by 30°C) than items made of alloy Nimonic 95. If the following conditions of testing be accepted for comparison: stress 7.5 kg to mm^2 and the time period until destruction of not less than 100 hours, then samples of alloy Nimonic 80A endure this test at a temperature not above 870°C, while samples of alloy Nimonic 90 stand it at 900°C, of alloy Nimonic 95 - at 920°C, of alloy Nimonic 100 - at 950°C. The results of tests for short-time tensile strength and for fatigue at high temperatures of alloy Nimonic 1000 are given in tables 47 and 48. The comparison of tensile strengths for a period of 100 hours for alloys of nimonic type (80, 80A, 90, 95 and 100) is shown in figure 142.

Changes in alloys of type Nimonic have quite a complicated character and can be studied only by means of very fine methods of Roentgen (X-ray) investigation (Yu. A. Bagriatskiy). During recent years Beily has carried out an electronic-microscopic investigation of alloys of the Nimonic type, using special methods of preparing the surfaces of the object and bubble (aluminum -

Table 45. Characteristics of tensile strength and creep of alloy Nimonic 95 (Tillog)

1) Test temperature, in °C; 2) Stress (or strain) in kg/mm^2 causing an elongation in % of; time in hours;
3) Limit of tensile strength in kg/mm^2, with a duration of test in hours;
4) Minimum rate of creep in % per hour, with a test duration of 100 hours.

Table 46. Results of tests for heat-endurance of alloy Nimonic 100 after thermal treatment

1) Test temperature, in °C; 2) Stress (or strain) in kg/mm^2 causing a deformation of: , during a time period in hours:
3) Limit of tensile strength, in kg/mm^2 for a period in hours:

4) Note: in parentheses () figures obtained by extrapolation are given.

Fig. 142. Comparison of tensile strengths of alloys of type Nimonic (80, 80A, 90, 95 and 100) for 100 hours.

Ordinate: limit of strength, in kg/mm²

Abscissa: Temperature, °C

aluminum oxide) replicas. The existence of very find dispersions of the second phase was established. The size of second-phase particles was found. So, after (illegible) hours of aging at 800°C the nominal magnitude of dispersions amounted to 0.05 mk.

Table 47. Results of short-time tests for stretching of alloy Nimonic 100 at high temperatures.

1) Test temperature, in °C; 2) Yield point (0.1%) 0.1, in kg/mm²;
3) Limit of strength, in kg/mm²; 4) elongation (or stretch) in %;
5) Narrowing of cross-section, in %; 6) Modulus of resilience $E.10^3$ in kg/mm²

Table 48. Results of tests for fatigue (torsion with bending) of alloy Nimonic 100 at high temperatures

1) Test temperature, in $^{\circ}C$; 2) Stress (or strain), in kg/mm^2;
3) destruction from the number of cycles 15.10^6 (100 hours);
4) Temperature, in $^{\circ}C$; 5) Strain (or stress) in kg/mm^2;
6) Destruction from the number of cycles

During the study of the influence of aging conditions upon the average size (or magnitude) of these dispersions it was shown that for all investigated brands of alloys of the Nimonick type the nominal average diameter of second-phase particles grows exponentially with the change of aging temperature between 750 and 875°C and that it grows much more slowly with a change of duration at constant temperature. The quantity of dispersions (the number of particles to an area unit of the polished micro-section) decreases lineally, but sufficiently fast with an aging temperature of from 700 to 800°C.

Between 850 and 900°C the decrease proceeds slower, while above 900°C the particles of the second phase disappear completely (going into the hard solution).

It was noted that alloys resist creep better in proportion to the decrease of the average distance between particles of the second phase.

An investigation of the influence of plastic deformation, which was made on samples subjected to 300 hours of aging at 900°C and to compression under pressure of 4 tons to the square cm has disclosed (apart from lines of slip and some polyginization in the master die (or matrix)), that the lines of slip cross the dispersions and that, in dispersions coherent with the matrix (or die), slipping takes place over the same planes. In this case the dispersions to not block the slip lines.

NATIONALLY PRODUCED HEAT-ENDURING AND HIGH-TEMPERATURE OXIDATION-RESISTANT ALLOYS BASED ON NICKEL

Alloys EI437, EI437A and EI437B. Our industry produces chrome-nickel-titanium alloys of type 20-77-2.5 to which are given index identification numbers EI437, EI437A and EI437B. Alloy EI437A is smelted out of purer mixture materials than is alloy EI437 and therefore has greater heat-endurance. Alloy EI437B contains additionally 0.005 to 0.008% of boron.

Alloy EI437 has its maximum tensile strength after having been tempered at a temperature of from 1080°C and aged at 700°C during 16 hours (fig. 143). An increase as well as a decrease of tempering temperature leads to a sharp lowering of durable strength.

Fig. 143. The influence of tempering temperature upon the tensile strength of alloy EI437. Before the test the samples were subjected to aging at 700°C during 16 hours.

1 - 600°C, σ = 600 kg/mm²; 2 - 700°C, σ = 36 kg/mm²; 3 - 800°C, σ = 20 kg/mm²; 4 - 850°C, σ = 15 kg/mm²

Ordinate: Time until destruction, in hours

Abscissa: Temperature, °C

Alloy EI437 has the following characteristic peculiarity: if the alloy aged at a temperature to 700°C is heated to a higher temperature (800 or 900°C), it loses a considerable amount of time strength. However by subsequent heating to a temperature of 700°C its mechanical properties are practically restored in full, that is a return of properties takes place.

The properties of alloy EI437A are given in fig. 144. These properties are somewhat higher than those of alloy EI437.

Testing of alloy EI437A for creep has shown that the residual deformation after 100 hours at a temperature of 700°C and a stress (or strain) of 30 kg to mm² fluctuates within the limits of 0.063 to 0.211% in dependence upon the hardness of the smeltings (or smelting batches).

Alloy EI437A has higher and more constant characteristics of fatigue resistance than alloy EI437. Almost in all cases the fatigue limit of alloy EI437A exceeds 35 kg to mm^2.

The properties of the most widely used alloy EI437B (with a small addition of boron) are given in fig. 145 to 149.

Fig. 144. Changes in the mechanical properties of alloy EI437A with increases in temperatures of short-time tests for elongation

Ordinate: in kg/mm^2, limits of

Abscissa: Temperatures, ^{o}C

Fig. 145. Mechanical properties of alloy EI437B at high temperatures, σ 100 and σ 1000 - tensile strength for 100 and 1000 hours.

Ordinate: Limit, in kg/mm^2

Abscissa: Temperature, ^{o}C

As investigations by N. I. Bulygin, E. P. Trusova and P. M. Sileverstova have shown, that the addition to alloys of type EI437 of small quantities of boron lead to great strengthening of grain limits. The transition from transcrystalline to intercrystalline breaks comes, when the test is of long duration, in alloy EI437 at 450°C and in alloy EI437B approximately at 600°C. In case of a short-time tensile strain, these temperature limits of transition from destruction across the grains to destruction along the edges of grains amount for alloys EI437 and EI437B correspondingly to ~700 and ~850°C. Hence comes the greater heat-endurance of alloy EI437B (fig. 150).

Fig. 146. Tensile strength of alloy EI437B

Ordinate: limit of strength, in kg/mm^2

Abscissa: hours

It must be noted that alloys of type EI437, like all other austenitic alloys, are to a great extent susceptible to hammer hardening, and can harden to a considerable degree even in mechanical processing on machines (surface impact hardening).

Fig. 147. Creep curves of alloy EI437B at test temperature of 650°C. 1 - σ = 50 kg/mm^2; 2 - = 47 kg/mm^2; 3 - σ = 45 kg/mm^2; 4 - σ = 40 kg/mm^2 5 - σ = 30 kg/mm^2

Ordinate: limit or δ, in %

Abscissa: hours

Fig. 148. Creep curves of alloy EI437B at test temperature of 700°C 1 - σ = 42 kg/mm^2; 2 - σ = 40 kg/mm^2; 3 - σ = 35 kg/mm^2. 4 - σ = 30 kg/mm^2; 5 - σ = 25 kg/mm^2.

Ordinate: limit or δ, in %

Abscissa: hours

Because surface impact hardening increases the diffusional mobility of atoms and also, probably, contributes to the formation on the surface of micro-cracks, the conditions of mechanical processing must be so adjusted as to reduce to the minimum the surface cold hardening of vanes made of alloys of type EI437 while they are being made on machines.

Alloy EI617 has the following composition: 0.80% C, 15% Cr, 5.0% Fe, 2% Ti, 2% Al, 3% Mo, 7% W, 0.008% B, 3% V. The highest level of heat-endurance of alloy EI617 is attained as a result of the following thermal treatment:

Fig. 149. Creep curves of alloy EI437B at test temperature of 800°C $1 - \sigma = 20$ kg/mm^2; $2 - \sigma = 18$ kg/mm^2; $3 - \sigma = 15$ kg/mm^2

Ordinate: δ %

Abscissa: hours

Fig. 150. Tensile strength of alloys EI437 (1) and EI437B (2)

Ordinate: limit of strength, in kg/mm^2

Abscissa: hours

first tempering - heating to 1200°C (during 2 hours), cooling in air; second tempering - heating to 1050°C during 4 hours, cooling in air; aging at 800°C during 16 hours, cooling in air.

An investigation of the influence of temperatures upon the properties of alloy EI617 made it possible to establish that the dissolution of excessive phases begins at temperatures above 1000°C. The influence of the conditions of thermal treatment upon tensile strength is characterized by the diagram on figure 151.

Fig. 151. The influence of thermal treatment upon the tensile strength of alloy EI617. Thermal treatment: (from left to right) a) - tempering at from 1200°C during 2 hours, cooling in air; b) - tempering at from 1200°C during 2 hours, cooling in air, aging at 800°C during 15 hours; c) - first tempering at from 1200°C during 2 hours, cooling in air, second tempering at 1050°C during 4 hours, cooling in air; d) - first tempering at from 1200°C during 2 hours, cooling in air, second tempering at 1050°C during 4 hours, cooling in air, aging at 800°C during 16 hours.

1 - test at 700°C, $\sigma = 45$ kg/mm^2; 2 - test at 800°C, $\sigma = 25$ kg/mm^2; 3 - test at 850°C, $\sigma = 20$ kg/mm^2.

Ordinate: Time, in hours
Abscissa: Thermal treatments a), b), c) and d)

The properties of alloy EI617 at high temperatures are shown in fig. 152 to 156.

The alloy has some susceptibility to notching at 700°C, while at 800°C and above the susceptibility to notching is absent (table 49).

The fatigue limit of alloy EI617 is found by bending on the basis of 10.10^6 cycles on smooth and on notched samples and amounts to:

a) for smooth samples at 700°C to 37 - 40 kg/mm², at 600°C to 35 - 3[illegible] kg/mm²,

b) for notched samples at 700°C to 28 - 31 kg/mm², at 800°C to 30 kg/mm².

Fig. 152. Mechanical properties of alloy EI617 at high temperatures (illegible)

Ordinate: limit, in kg/mm²

Abscissa: Temperatures, °C

Fig. 153. Tensile strength of alloy EI617

Ordinate: limit of strength, in kg/mm²

Abscissa: hours

Fig. 154. Creep curves of alloy EI617 at a test temperature of 700°C

1 - σ = 40 kg/mm^2; 2 - σ = 35 kg/mm^2; 3 - σ = 30 kg/mm^2

Ordinate: δ %

Abscissa: hours

Fig. 155. Creep curves of alloy EI617 at test temperature of 800°C

1 - σ = 23 kg/mm^2; 2 - σ = 18 kg/mm^2; 3 - σ = 15 kg/mm^2.

Ordinate: δ %

Abscissa: hours

The alloy is highly resistant to corrosion by gases.

When samples are kept for a long time in air at 900°C the increase in weight amounts to 0.085 g/m^2/hour, and at 1000°C to 0.58 g/m^2/hour.

Fig. 156. Creep curves of alloy EI617 at test temperature of 850°C
1 - σ = 18 kg/mm^2. 2 - σ = 17 kg/mm^2;
3 - σ = 14 kg/mm^2; 4 - σ = 11 kg/mm^2.

Ordinate: δ %

Abscissa: hours

Fig. 157. Tensile strength of alloy EI598

Ordinate: limit of strength, in kg/mm^2

Abscissa: hours

Table 49. Sensitiveness to notching (or cutting) of alloy EI617

1) Type of sample: (a) Smooth; (b) Notched; (c) Smooth; (d) Notched; (e) Smooth; (f) Notched (or with a cut)

2) Results of tests for tensile strength: (a) Test temperature, in °C; (b) σ in kg/mm^2; (c) Resistance of different smelting batches in hours (until destruction)

Alloy EI598 has the composition of 0.08% C, 15% Cr, $\leq$ 5.0% Fe, 2.5% Ti, 1.5% Al, 6% W, 3% Mo, 0.008% B. The alloy has found a limited use for making working vanes of gas turbines. At common room temperatures alloy EI598 is close to alloy EI617, but it has somewhat greater plasticity. At temperatures of from 750 to 800°C alloy EI598 has, besides high heat-endurance, also sufficiently high plasticity and is recommended for working within the range of these temperatures. At temperatures of 850 to 900°C this alloy is somewhat inferior to alloy EI617 in tensile strength and resistance to creep. The curves of tensile strength of alloy EI598 are presented in figure 157.

Fig. 158. Mechanical properties of alloy EI826 at high temperatures (short-time tests for stretching)

Markings at curves (from top): 1) time limit, 2) "E" dynamic

3) "E" static

Alloy EI826 (EI617 AB) The changes in the mechanical properties of alloy EI826 at increased test temperatures are shown in fig. 158, and the tensile strength of the alloy at 700, 800 and 900°C is shown in fig. 159. The curves of creep and endurance are given in fig. 160 and 161.

From the comparison of all these data it follows that alloy EI826 has very high heat-enduring properties within a wide range of temperatures.

Alloy EI826 is harder to deform in a hot state than alloys EI617 and EI437B, but its deformation is quite possible, if the number of intermediate stamping dies and the number of heatings be increased.

Alloy VZh17 has the composition of 15% Cr, 10% W, 1% V, 1% Nb, 3% Al and 0.008% B. At 800°C and σ = 30 kg/mm^2. Its tensile strength is of the order of 80 to 160 hours. When the content of aluminum was increased (to 4%) it was difficult to deform the alloy, but in cast form at 950°C and σ = 15 kg/mm^2 it had a durability of over 100 hours. It is a characteristic peculiarity of the alloy, that both in the cast and in the deformed state it has, besides high heat-endurance, also a high plasticity within a wide range of temperatures.

The limits of tensile strength of heat-enduring steels and alloys used in domestic industry are presented in fig. 162.

Fig. 159. Tensile strength of alloy EI826 at 700 - 900°C

Ordinate: limit of strength, in kg/mm^2 Abscissa: hours.

Fig. 160. Creep curves of alloy EI826 at test temperatures a) 800°C; b) 900°C

Ordinate: δ % Abscissa: hours

Fig. 161. The results of testing smooth samples of steel EI826. (Г) smooth samples, (Н) notched samples

Ordinate: illegible Abscissa: Number of cycles until destruction

Fig. 162. Tensile strength of some brands of heat-resisting steels and alloys used in domestic industry for a duration of 100 hours

Ordinate: 100 hour limit, in kg/mm^2 Abscissa: Temperature, °C

At curves (from top-right to bottom-left): 1) EI617AB (EI826), 2) EI437B, EI617, 3) EI696, EI437B, 4) EI481, EI437, EI388, 5) EI388, EI391, 6) EI415

ALLOYS ON THE BASIS OF COBALT

Deformable alloys.

Alloy Refractalloy 70 contains: 0.01% C, 21% Ni, 20% Cr, 30% Co, 14% Fe, 8% Mo, 4% W, 2% Mn, 0.3% Si. The thermal treatment of the alloy consists of tempering at from 1260°C (during 4 hours), cooling in oil and aging at 815°C during 24 hours. The final hardness H_B = 293 ÷ 352. The results of testing Refractalloy 70 for tensile strength and creep after thermal treatment are presented in fig. 163.

Fig. 163. The limits of strength and creep of alloy Refractalloy 70

1 - strength for 100 hours; 2 - strength for 1000 hours; 3 - limit of creep with a deformation speed of 1% for 100 hours; 4 - limit of creep with a deformation speed of 1% for 1000 hours.

Ordinate: Limit of strength, in kg/mm² Abscissa: Temperature, °C

Alloy S-816 contains 0.4% C, 20% Ni, 19% Cr, 41% Co, 3% Fe, 4% Mo, 4% W, 4% Nb (or Nb + Ti), 1.5% Mn, 0.6% Si. The thermal treatment of the all· consists of tempering at from 1200°C to 1250°C during one hour, cooling in water, aging at 760°C during 16 hours. Hardness after thermal treatment is H_B = 248 - 331.

The results of tests for tensile strength and creep are given in fig. 164.

For alloy S-815 (like for many other heat-enduring alloys) a great susceptibility of heat-enduring properties to the conditions of thermal treatment, and especially to tempering temperature, was established. So, the limit of creep of alloy S-816 increases with an increase of tempering temperature from 1150 to 1250°C.

Alloy Heiness-alloy 25 contains up to 0.15% C, 9 to 11% Ni, 19 to 21% Cr, up to 2% Fe, 14 to 16% W, 1 to 2% Mn, 1.0% Si, the remainder being cobalt. The alloy yields to deformation with great difficulty at temperatures of the order of 1200°C. After forging, it must be subjected without fail to annealing at 1050 to 1100°C in order to remove inner stresses. The thermal treatment consists of annealing, usually at 1230°C, more seldom at 800 to 900°C. The results of tests for creep of Heiness-alloy 25 are given in table 50.

Fig. 164. Limits of strength and creep of alloy S-816.

a) tensile strength, b) limit of creep

Ordinate: Limits of strength, of creep, in kg/mm^2

Abscissa: hours.

Legend (top-right): Rate of creep 10^{-4}%/hour

Cast alloys.

Vitallium or HS -21 has many modifications of chemical composition. Therefore below are given the limiting values of the content of elements: 0.2 to 0.35% C, 1.5 to 3.5% Ni, 25 to 30% Cr, up to 2% Fe, 4.5 to 6.5% Mo, (illegible) .3% Mn, 0.6% Si, the remainder being cobalt. Most often the thermal treatment of Vitallium consists of aging of castings at 730 to 876°C during 50 hours for a hardness $H_{R_A} = 65 \div 70$. More seldom annealing is done at 1150 to 1230°C. The results of tests for short-time tensile strength, creep and durable strength are given in tables 51 and 52.

Table 50. Characteristics of creep of alloy HA-25

1) Test temperature, in °C; 2) tests for creep; 3) stress (or strain) in kg/mm²; 4) Speed of creep in % for 1000 hours, with a duration of test in hours

Table 51. Mechanical properties of alloy HS-21 (Vitallium) at heightened temperatures

1) Short-time tests for extension: 2) Test temperature, in °C;

3) Treatment condition: (a) Cast, (b) Aged at 735°C during 50 hours, (c) Same 4) Limit of strength, in kg/mm²

5) Limit of creep, in kg/mm² 6) Limit of proportionality, in kg/mm²

7) Relative elongation, in % 8) Tests for tensile strength

9) Test temperature, in °C 10) Treatment condition: (a) cast; (b) aging at 815°C during 50 hours; (c) same.

11) limit of elongation strength kg/mm² duration of test 1 hour

Table 52. Creep characteristics of alloy HS-21 (Vitallium) at heightened temperatures

1) Test temperature, in °C 2) Treatment condition: (a) cast; (b) aged (c) aged at 815°C during 50 hours; (d) aged at 870°C during 50 hours; (e) same.

3) Stress (or strain), in kg/mm^2 4) Initial deformation, in %

5) Rate of creep in % for 1000 hours, in test duration of hours:

6) General deformation, in %, for the period in hours:

Alloy 61 or HS-23: 0.35 to 0.5% C, up to 1.5% Ni, 23 to 29% Cr, up to 2% Fe, 4 to 7% W, 0.3% Mn, 0.6% Si, the remainder being cobalt. Thermal treatment: aging of castings at 730 to 870°C during 50 hours for obtaining a hardness $H_{R_A} = 65 \div 70$. Maximum hardness $H_{R_C} = 32 \div 42$ is obtained as result of aging at 800°C during 25 hours. Annealing is done at 1150 to 1230°C. The mechanical properties of alloy HS-23 at high temperatures, obtained in consequence of short-time and long tests for tensile strength, are given in tables 53 and 54,

Tables 53. Mechanical properties of alloy HS-23 (No. 61) at heightened temperatures

1) Short-time tests for extension (ductility) 2) Test temperature, in °C

3) Treatment condition: (a) cast, (b) aged at 735°C during 50 hours, (c) same

4) Limit of strength, in kg/mm^2 5) Yield point, in kg/mm^2

6) Limit of proportionality, in kg/mm^2

7) Elongation (or stretching), in %

(1) Continuation of table 53 2) Tests for tensile strength

3) Test temperature, °C 4) Processing condition: (a) cast,

(b) aged at 815°C during 50 hours, (c) aged at 870°C during 50 hours,

(d) same. 5) Limit of tensile strength in kg/mm^2 for a test period in hours.

Table 54. Creep characteristics of alloy HS-23 (No. 61)

1) Test temperature, in °C   2) treatment condition: (a) aging at 735°C for 50 hours, (b) same, (c) aging at 815°C during 50 hours, (d) aging at 870°C during 50 hours (e) same

3) Stress, in kg/mm^2 4) Initial deformation, in %

5) Speed of creep in % for 1000 hours, with a duration of test in hours

6) General deformation in %, for a time in hours.

Alloy 6059 or HS-27 contains: 0.35 to 0.5% C, 30 to 38% Ni, 23 to 29% Cr, 30 to 32% Co, up to 2% Fe, 5 to 7% Mo, 0.5% Mn, 0.4% Si. Thermal treatment: aging at 730 to 815°C during 24 hours. Hardness H_{R_A} = 60 ÷ 67. Maximum hardness H_{R_C} = 26.5 ÷ 30.5 is obtained after aging at 800°C during 5 hours. Annealing is done at 1150 to 1230°C. The results of tests for short-time elongation, tensile strength, and creep are given in tables 55 and 56.

Alloy 422-19 or HS-30 contains: 0.35 to 0.5% C, 13 to 17% Ni, 23 to 29% Cr, 30 to 32% Co, up to 2% Fe, 5 to 7% Mo, 0.5% Mn, 0.4% Si, the remainder being

cobalt. Thermal treatment: aging at 815 to 930°C during 50 hours. The hardness obtained is $H_{R_A} = 65 \div 72$. Maximum hardness $H_{RC} = 27 \div 36.5$ is obtained after aging at 800°C during 5 hours. Annealing of the alloy is done at 1150 to 1230°C. Data concerning tests for short-time elongation, tensile strength, and creep are given in tables 57 and 58.

Alloy X-40 or HS-31 contains: 0.45 to 0.6% C, 9 to 12% Ni, 23 to 28% Cr, up to 2% Fe, 6 to 9% W, 0.6% Mn, 0.7% Si, the remainder being cobalt. Thermal treatment: aging at 815 to 930°C during 50 hours. Hardness $H_{R_A} = 64 \div 70$. Maximum hardness $H_{R_A} = 28 \div 41$ is obtained after aging at 800°C during 25 hours. Annealing is done at 1150 to 1230°C. Data concerning mechanical properties at heightened temperatures are shown in tables 59 and 60.

A comparison of heat-resistant properties of some cobalt and nickel alloys may be made by reviewing the graphs in fig. 165 to 167.

ALLOYS BASED ON CHROME

Alloys based on chrome, particularly those pertaining to the system chrome-molybdenum-iron, have very high heat-endurance and heat-resistance.

However the high brittleness of chrome and of alloys on its bases, possibly in consequence of the presence of oxygen and nitrogen, sharply limits the use of these materials for parts of gas turbines, reactive motors and rockets.

Table 55. Mechanical properties of alloy HS-27 (No. 6059) at heightened temperatures

1) Short time tests for extension (ductility)

2) Test temperature, in °C

3) Treatment condition: (a) case, (b) aged at 735°C during 50 hours, (c) same, (d) aged at 925°C during 50 hours, (e) same.

4) Limit of strength, in kg/mm²

5) Yield point, in kg/mm²

6) Limit of proportionality, in kg/mm²

7) Relative elongation in %

8) Test for tensile strength

9) Test temperature, in °C

10) Treatment condition: (a) case, (b) aged at 815°C during 50 hours, (c) same, (d) cast

11) Limit of tensile strength, in kg/mm² for a test period of hours

Table 56. Creep characteristics of alloy ES-27 (No. 6059)

1) Test temperature, °C
2) Treatment condition: (a) aging at 735°C during 50 hours,
   (b) same, (c) aging at 815°C during 50 hours, (d) same.
3) stress (or strain), in kg/mm^2
4) Initial deformation, in %
5) Speed of creep in % for 1000 hours, in a test period of hours
6) General deformation in % for a time in hours

In consequence of a heightened content of admixtures, chrome obtained by de-oxidation from chrome oxide (for instance by the alumothermic method) cannot be considered as usable for the production of heat-enduring alloys. Other methods of obtaining chrome are used, in which the contamination by cases is decreased.

1. De-oxidation of chrome oxide with metallic calcium or hydrate of calcium in a massive iron crucible at 900°C. The reduced mass, obtained in consequence of the reaction, is taken out from the crucible and is treated with acids to remove calcium oxide. The chrome powder that is being formed contains a somewhat lowered quantity of oxygen.

Table 57. Mechanical properties of alloy HS-30 (No. 422-19) at heightened temperatures

1) Short time tests for extension
2) Test temperature, °C
3) Treatment condition: (a) cast, (b) aging at 735°C during 50 hours,
(c) same, (d) aging at 925°C during 50 hours
4) Limit of strength, in kg/mm²
5) Yield point, in kg/mm²
6) Limit of proportionality, in kg/mm²
7) Relative elongation (or stretching), in %
8) Tests for tensile strength
9) Test temperature, °C
10) Treatment condition: (a) aging at 735°C, (b) same,
(c) aging at 815°C during 50 hours,
(d) same, (e) cast
11) Limit of tensile strength, in kg/mm², in a test period of hours

Table 58. Creep characteristics of alloy HS-30 (422-19)

1) Test temperature, °C
2) Treatment condition: (a) cast, (b) aging at 735°C during 50 hours,
(c) cast, (d) aging at 735°C during 50 hours,
(e) aging at 815°C during 50 hours, (f) same,
(g) aging at 870°C during 50 hours, (h) same
3) strain (or stress), in kg/mm^2
4) Initial deformation, in %
5) Speed of creep in % for 1000 hours, for the time in hours
6) General deformation, in % for the time in hours.

2. The de-oxidation (or reaction) of chrome chloride, especially purified of oxygen, with metallic magnesium within an atmosphere of helium. By-products formed during this reaction are sublimated in a high vacuum.

3. Volatilization of a specially purified iodide of chrome in glass or metal tubes with condensation of pure chrome on a tungsten filament.

4. The purification in hydrogen of a powder of electrolytic chrome obtained from electrolysis of an aqueous solution containing 250 to 300 g/l

Table 59. Mechanical properties of alloy HS-31 (X-40) at heightened temperatures

1) Short-time tests for extension
2) Test temperature, °C
3) Treatment condition: (a) cast, (b) aging at 735°C during 50 hours, (c) same
4) Limit of strength, in kg/mm^2
5) Yield point, in kg/mm^2
6) Limit of proportionality, in kg/mm^2
7) Relative elongation, in %
8) Tests for tensile strength
9) Test temperature, °C
10) Treatment condition: (a) cast, (b) aging at 735°C during 50 hours, (c) aging at 815°C during 50 hours, (d) aging at 815°C during 50 hours, (e) cast
11) Limit of tensile strength, in kg/mm^2 in a test duration of hours.

Table 60. Creep characteristics of alloy HS-31 (X-40)

1) Test temperature, °C
2) Treatment condition: (a) cast, (b) aging at 815°C during 50 hours,
(c) same, (d) aging at 870°C during 50 hours
3) Strain (or stress), in kg/mm^2
4) Initial deformation, in %
5) Speed of creep, in % for 1000 hours, for the time period of hours
6) General deformation, in % for the time in hours.

of chrome oxide and 2.5 to 4.0 g of sulphate at a temperature of 80 to 85°C and a current of 1.19 a/cm^2.

The three latter methods make it possible to obtain chrome of such high purity that in a number of cases it becomes deformable.

For the smelting of chrome alloys in an inert atmosphere (best of all in helium) an arc furnace is used. The electrode used is of tungsten covered with thorium. It is fastened to a water-cooled electrified holder. The crucible of the furnace is made of pure copper.

Fig. 165. Limits of strength for a period of 100 hours for some heat-resistant alloys of nickel and cobalt

1 - Inconel X; 2 - Refractalloy 26; 3 - N (or HA) - 25; 4 - HS-31;
5 - M-252; 6 - HS-21

Ordinate: limit of strength, in kg/mm^2

Abscissa: Temperature, °C

Fig. 166. Limits of strength for a duration of 1000 hours for some heat-resistant alloys of cobalt and nickel

1 - Inconel X; 2 - Refractally 26; 3 - HA-25; 4 - HS-31
5 - M-252; 5 - HS-21

Ordinate: Limit of strength Abscissa: Temperature, °C

Fig. 167. Creep limit causing an elongation of 1% for 10,000 hours (0.0001% per hour) for some cobalt and nickel alloys

1 - Inconel X, 2 - Refractally 26, 3 - HS-25, 4 - HS-31, 5 - HS-21

Ordinate: creep limit, in kg/mm^2

Abscissa: $^{\circ}$C

There are announcements of the practical use of alloys containing 60% Cr, 25% Mo and 15% Fe. With a stress of 12.5 kg to mm^2 and a temperature of 900°C the time until the destruction of an alloy of the composition mentioned exceeds 1500 hours. At 930°C and a stress (or strain) of 20 kg to mm^2 this time measures several hundreds of hours. At such high temperature the alloys investigated have limited plasticity: the elongation and narrowing of cross-section after rupture amount to 5% each. The optimum (or best) combination of strength and plasticity is obtained when the alloy contains

$\leq 0.05\%$ C, $\leq 0.2\%$ Si and traces of O_2 and N_2. As tests show, a decrease of grain size contributes to an increase of tensile strength and plasticity.

A careful preparation of samples and, most important, the alloy's purification of admixtures has a very great significance. If samples of alloys containing 50% Cr, 2.5% Mo and 15% Fe are prepared with all precautions, they have a 100 hour limit of tensile strength at 1000°C and a stress (or strain) of 15.4 kg to mm^2. Some physico-mechanical properties of an alloy containing 60% Cr, 25% Mo and 15% Fe are given below.

The hardness in a cast state is $H_n = 498$; at 600°C $H_n = 430$; at 700°C $H_n = 396$; at 870°C $H_n = 296$; at 930°C $H_n = 274$. The density is 7, 87 g to cm^2. The modulus of normal resiliency E 2.6.10^4 kg/mm^2. The average coefficient of thermic expansion is:

within the range of 24 - 150°C ... 6.41.10^{-6} mm/mm degrees
24 - 480°C ... 7.49.10^{-6} mm/mm degrees
24 - 815°C ... 8.66.10^{-6} mm/mm degrees

The results of tests of a number of chrome alloys for creep under conditions of compressing stresses are presented in figures 168 and 169.

In analyzing the results of these tests, it must be admitted that chrome alloys, which have certainly a high potential of usability as a

Fig. 168. Creep of some chrome alloys under compressing stress of $3\ kg/mm^2$ at 900°C

1 - 10% Fe, 10% Ta; 2 - 10% Fe, 5% Ta; 3 - 10% Fe, 15% Ta;
4 - 20% Fe, 15% Ta; 5 - 20% Fe, 28% Ta.

Abscissa: hours

Fig 169. Creep of some chrome alloys under compressing stress of $8\ kg/mm^2$

1 - 10% Fe, 10% W, 10% Ta; 2 - 10% Fe, 10% W, 5% Ta; 3 - 10% Fe, 15% Mo;
4 - 10% Fe, 10% Mo; 5 - 10% Fe, 5% W, 5% V.

Abscissa: hours

highly heat-enduring material, require exceptional care in carrying out the technological operations of smelting and further processing. Evidently, a change in the composition of these alloys, the addition to their composition, besides molybdenum and iron, also of a number of other elements is completely rational. It may be considered, that such a complex alloying will lead not only to an increase of heat-enduring properties of the chrome alloys, but also to a decrease of their brittleness.

ALLOYS ON THE BASIS OF TITANIUM

In recent times the volume of works concerning the use of titanium and its alloys has considerably increased. In a number of cases the utilization of these alloys is contemplated also for work at heightened temperatures.

The basic advantage of titanium alloys is their small specific weight, which determines lower specific stress during the action of centrifugal forces, but corresponds to working conditions, for instance, of any parts of gas turbines (discs and vanes).

The results of short-time tests of industrially pure titanium for tensile strength at room and heightened temperatures are given in table 61.

Figures 170 and 171 present curves obtained from tests of titanium for creep and tensile strength.

Table 61. Mechanical properties of pure titanium, obtained through tests of flat samples cut out from annealed sheets

1) Test temperature, $^{\circ}C$
2) Limit of strength, in kg/mm^2
3) Yield point, in kg/mm^2
4) Relative elongation, in %
5) Narrowing of cross-section, in %
6) Modulus of nominal resilience $E \cdot 10^4$, in kg/mm^2

Composite table 62 gives data concerning the durability of alloys of titanium with manganese, aluminum, iron, chrome, molybdenum or tin when these alloys are heated. Figures 172 and 173 show the limits of durable strength for alloys of titanium with 3% Al and 5% Cr ($\leq$ 0.5% C), as well as of the alloy of titanium with 2.7% Cr and 1.3% Fe ($\leq$ 0.02% C, 0.5% O_2, 0.04% N_2). Tensile strength of more complicated titanium alloys is presented in the diagram fig. 174 and in table 63.

increases heat-endurance up to 1000-1100°C. However heat-endurance of the steel is comparatively low (fig. 91).

Fig. 88. Limits of tensile strength (1) and of creep (2) in steel of type 18-8 at 430°C. Preliminary treatment of samples: cold hardening by rolling with a compression extent of 40% at 76°C. Upper curve cross-cut samples; lower curve - longitudinal samples.

Ordinate: limit of strength, in kg/mm^2

Abscissa (on top): Rate of creep, % per hour

(at bottom): hours

Fig. 89. Creep limit of chrome-nickel austenitic steels of type 20-25 at 10^{-5}/h (1), of type 25-20 (2), of 17-37 (3), and of 11-36 (4).

Ordinate: limit of creep, in kg/mm^2

Abscissa: °C

Table 62. Mechan properties of some titanium alloys at heightened temperatures

1) Composition of alloy
2) Test temperature, °C
3) Limit fo strength, in kg/mm^2
4) Yield point, in kg/mm^2
5) Relative elongation, in %
6) Modulus of normal resilience, E $.10^4$, in kg/mm^2
7) Stress in kg/mm^2 causing a deformation of 1% in 1500 hours

Fig. 170. Characteristics of creep and strength of titanium at 540°C. Figures at curves denote elongation (or stretching) in %

Ordinate: illegible

Abscissa: hours

Legend (at top right) Curve of strength.

Fig. 171. Strength of titanium at high temperatures; tests of flat samples.

Ordinate: % time

Abscissa: hours

Fig. 172. Strength for the duration of 1000 hours of a titanium alloy with 3% Al and 5% Cr (up to 0.5% C).

Ordinate: limit of strength, in kg/mm^2

Abscissa:. Temperature, °C

Fig. 173. Strength of titanium alloy containing 2.7% Cr, 1.3% Fe (up to 0.02% C, 0.5% O_2 and 0.04% N_2)

Ordinate: limit of strength, in kg/mm^2

Abscissa: hours

Fig. 174. Test for strength at 955°C of some complex alloys on the basis of titanium.

1 - 31.6% Cr, 17.8 Mo, 8.0 W, specific weight 6.21 kg/cm^3

2 - 5% Cr, 1.0% Mn, specific weight 4.65 kg/cm^3

3 - 38.6% Cr, 16.4% Mo, 8.0% W, specific weight 6.22 kg/cm^3

4 - 45.0% Cr, 16.4% Mo. 8.6% W, specific weight 6.81 kg/cm^3

5 - 50.0% Cr, 16.8% Mo, 8.6% W, specific weight 6.82 kg/cm^3

a) illegible

b) time until destruction

Left ordinate: bp - special time

Right ordinate: hours

Abscissa: serial numbers of alloys as considered above.

Table 63. Properties of complexly alloyed titanium alloys at heightened temperatures

1) Content of alloying elements

2) Thermal treatment: (a) aging at 650°C for one hour, (b) aging at 845°C for 3 hours, (c) aging at 650°C for 1 hour

3) Tensile strength, in kg/mm^2 at temperatures °C

4) Same for test duration in hours

MOLYBDENUM AND ITS ALLOYS

Until recent time molybdenum was used, basically, for making incandescent elements in special bulbs, but advances in the technology of making large parts of molybdenum by methods of powder metallurgy and by smelting in arc-vacuum furnaces have made it possible to raise the question of using molybdenum as a constructional material for making different stressed parts of machines and mechanisms. Taking into account the high temperatures of molybdenum's melting and re-crystallization points, as well as its high hardness in a hot state, the use of molybdenum and of alloys based on it, as heat-enduring materials must be considered as rational. However, a considerable defect of molybdenum and of its alloys is their vigorous oxidation at temperatures above 500 to 700°C. Thus, the basic problem determining the possibility of using molybdenum and its alloys as a heat-enduring material is the finding of methods for protecting them reliably against oxidation.

Taking into account the low resistance of molybdenum and its alloys to corrosion by gas, their mechanical tests at high temperatures are carried out in special installations, in which the sample being tested is in a vacuum.

The carrying out of short-time tests for tensile strength at high temperatures in a vacuum has already disclosed that both preliminary processing

and the method of obtaining molybdenum and its alloys bear an essential influence upon the characteristics of mechanical properties. Thus, annealing for re-crystallization lowers noticeably the limits of tensile strength at room and heightened temperatures and increase plasticity within a temperature range of from 850 to 1100°C (fig. 175). Even the difference in the conditions of clinkering of powdered molybdenum (in a vacuum or in hydrogen) exerts a definite influence upon mechanical properties. A comparison of deformation curves for molybdenum samples produced by methods of powder metallurgy and by the method of smelting in a vacuum furnace is shown in fig. 175. When the test temperature is lowered, the influence of the method of molybdenum production upon the course of deformation curves manifests itself with special sharpness. This gave a basis for carrying out serial tests of molybdenum for tensile strength at different temperatures (fig. 177). It turned out that the critical temperature of the transition of molybdenum from a ductile to a brittle state (determined basically by the values of relative contraction) is sufficiently high, a fact which must be taken into account in constructional calculations. Further tests have also shown that the critical temperature depends upon the speed of deformation, the conditions of stress, the size of the grain and the presence of impurities, in the first place of carbon,

oxygen and nitrogen, which form in molybdenum a hard solution.

Considering the fact that the conditions of molybdenum's production and processing strongly influence its properties, the results of tests for tensile strength (fig. 178) are shown in the form of cross-hatched zones of critical stresses. The lower limit of a zone corresponds to the re-crystallized state of the samples, the upper limit to the deformed state (after settling).

Data concerning short-time tests for tensile strength and creep are presented in tables 64 and 65.

Fig. 175. The influence of preliminary processing upon the limit of strength and elongation of molybdenum at room and heightened temperatures
Figures at curves denote elongation in %.
1 - Samples after shortening by [illegible]%;
2 - Samples after re-crystallization.

Fig. 176. Creep curves for samples of molybdenum produced by the method of smelting in an arc furnace (1) and by the method of powder metallurgy (2) Conventional symbols: Dots - upper limit of creep. Circlets - lower limit of creep. Triangles - limit of strength Squares - destruction.

Ordinate: Stress in kg/mm^2

Abscissa: Elongation (or stretching), in %

Fig. 177. Results of serial testing of molybdenum for stretching at different temperatures

Fig. 178. Tensile strength of molybdenum at 870-1000°C

Ordinates: Limit of strength, in kg/mm^2

Abscissa: hours

Table 64. Results of short-time tests for extension at high temperatures of samples of re-crystallized molybdenum

1) Test temperature, °C
2) Yield point, in kg/mm²
3) Limit of strength, in kg/mm²
4) Elongation, in %
5) Narrowing of cross-section, in %

Table 65. Creep of re-crystallized molybdenum

1) Test temperature, °C
2) Nominal stress, in kg/mm²
3) Time u[illegible] destruction, in hours
4) Minimal speed of creep in mm/mm per minute
5) Temperature of test, °C
6) Nominal stress, in kg/mm²
7) Time until destruction, in hours
8) Minimal speed of creep, in mm/mm per minute
9) Test temperature, °C
10) Nominal stress, in kg/mm²
11) Time until destruction, in hours
12) Minimal speed of creep in mm/mm per minute

Fig. 179 shows the results of tests for tensile strength of cast alloys of molybdenum with titanium, niobium and cobalt after their different thermal processing. For comparison the limits of the values of tensile strength of pure molybdenum are shown in the same figure. As it follows form experimental data, the rational alloying of molybdenum leads to a sharp increase of its heat-enduring properties.

A comparison of the limits of tensile strength of different heat-enduring metallic alloys and metallo-ceramic materials at 600 to 1100°C obtained from 1000 hour tests (fig. 180) shows, that the molybdenum alloys have the maximum heat-endurance, and that they may occupy a leading place among materials for service at high temperatures, if or when a method for their reliable protection against corrosion by gas is found.

Fig. 179. Results of testing for tensile strength in a vacuum at 870 (a),

Fig. 179 (continued).

980 (b) and 1093°C (c) of molybdenum alloy with titanium, niobium, vanadium or cobalt. The alloys with 2.46% Ti, 0.32% Nb, 0.85% V, 0.04% Co, 0.67% V and 2.4% Ti in the re-crystallized state are denoted correspondingly with little rhombuses (or diamonds), triangles with apexes up and down, circlets, squares and crosses. The filled (or solid) signs correspond to the same alloys after the inner stresses in them are eliminated.

Ordinate: strength, in kg/mm^2

Abscissa: hours

Fig. 180. Comparison of strength characteristics for 1000 hours of some heat-resistant materials at 650-1100°C

Ordinate: Limit of strength, in kg/mm^2

Abscissa: °C

Legends (from top to bottom) At left: 1) highly alloyed austenitic steels, 2) cast cobalt alloys, 3) Steel 18 CR - 8 Ni.

At right: 1) molybdenum steels, ceramic-metals.

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MAGNETIC MATERIALS

Depending upon the magnitude of the coercive force H_c, magnetic material are subdivided into magnetically soft and magnetically hard.

Magnetically soft materials have a coercive force H_c of from several oersteds to some thousandth parts of an oersted.

A small coercive force H_c is accompanied by large values of magnetic penetrability in weak and intermediate fields.

With the same maximum inductions the losses of hysteresis during reversal of magnetism in magnetically soft materials are many times lower than in magnetically hard materials.

BASIC TYPES OF MAGNETICALLY SOFT MATERIALS AND THE PROPERTIES REQUIRED OF THEM

1. Materials for magnetic conductors of direct current.

a) A high magnetic induction in intermediate and strong magnetic fields (from tens to hundreds of oersteds);

b) good machineability by cutting and pressure.

2. Materials for relays of direct current and magnetic screens:

a) High magnetic penetrability in weak and intermediate fields (from hundredth parts of an oersted to several tens of oersteds);

b) A small coercive force as a means of decreasing the seeming residual induction (for relays);

c) Machineability by cutting and pressure, in particular by bending for (or to) a small radius.

3. Materials for magnetic conductors of alternating current (for cores of transformers, relays, etc.)

a) Small specific losses during reversal of magnetism;

b) High magnetic induction in strong fields (for electric machines and power transformers);

c) High magnetic penetrability in weak and intermediate fields (from thousandth parts of an oersted to tens of oersteds);

d) A rectangular loop of hysteresis (magnetic amplifiers, contact rectifiers, contactless relays, etc.)

e) Good stampability (for sheet materials).